

SOFIA

Stratospheric Observatory for Infrared Astronomy

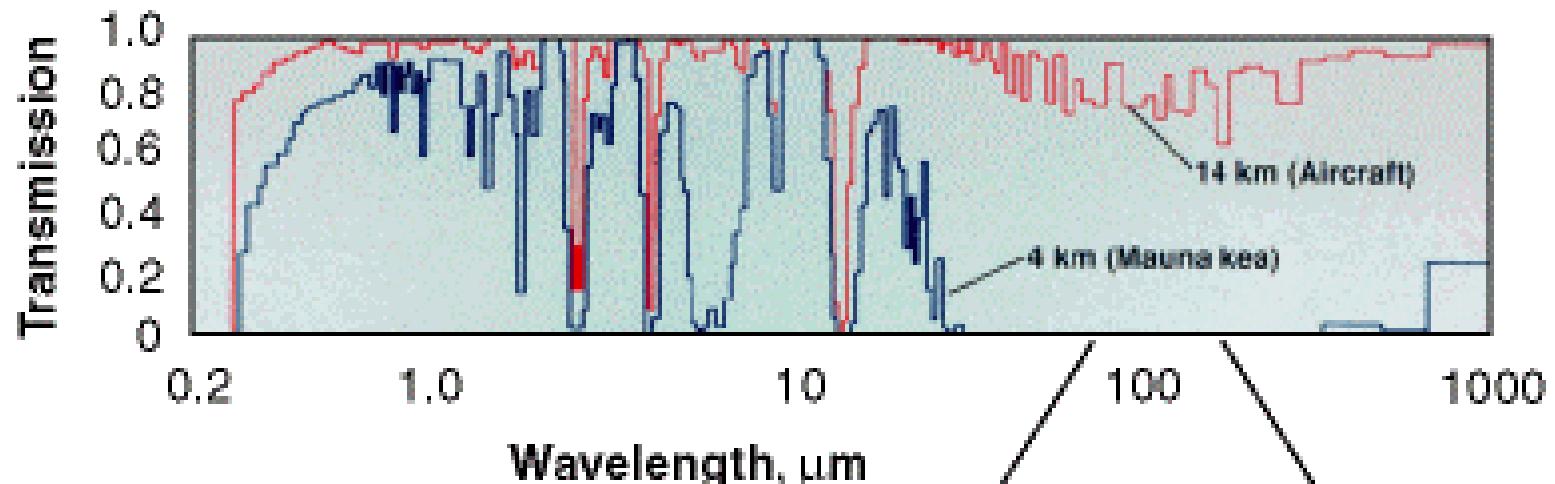


Jackie Davidson
(USRA SOFIA Project Scientist)

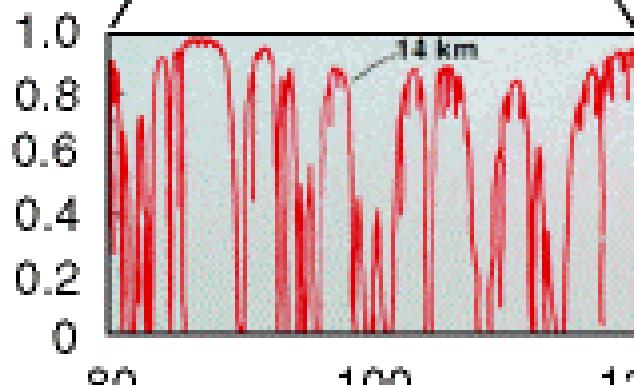
<http://sofia.arc.nasa.gov>

SOFIA Characteristics

- ***Wavelength range:*** UV - Radio ($0.3\mu\text{m}$ - $1600\mu\text{m}$) as defined by the atmosphere above flight altitude.



Many wavelength bands obscured from Earth are accessible from aircraft.



SOFIA Characteristics

- ***Wavelength range:*** UV - Radio ($0.3\mu\text{m}$ - $1600\mu\text{m}$) as defined by the atmosphere above flight altitude.
- ***Platform & Operating Altitude:*** Boeing 747SP; @ 37,000 - 45,000 ft
- ***Optical configuration:*** Bent Cassegrain with oscillating secondary mirror and flat folding tertiary mirror.
- ***Primary Mirror Ø:*** 2.7m (Aperture 2.5 m)
- ***Telescope emissivity:*** $\leq 10\%$ @ $10\ \mu\text{m}$ (without dichroic tertiary)
 - Optical transmission: $\geq 90\%$ (without dichroic tertiary)
- ***Operating temperature:*** 240 K

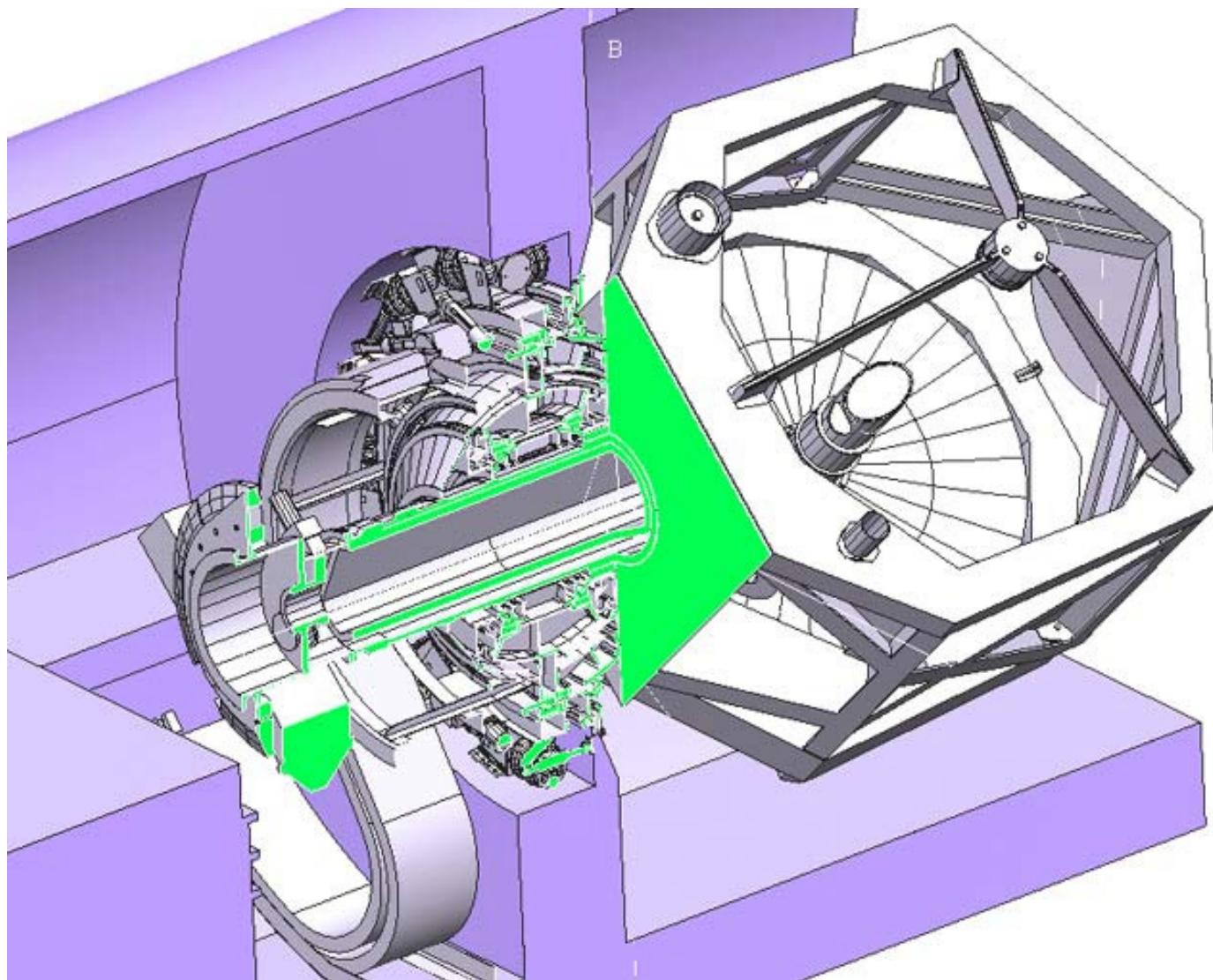
Observatory Lay-out



SOFIA Cavity - Waco January 2003



Telescope in Aircraft



Suspension Assembly (SUA) of Telescope - Augsburg May 2002



Installation of SUA - Waco February 2003

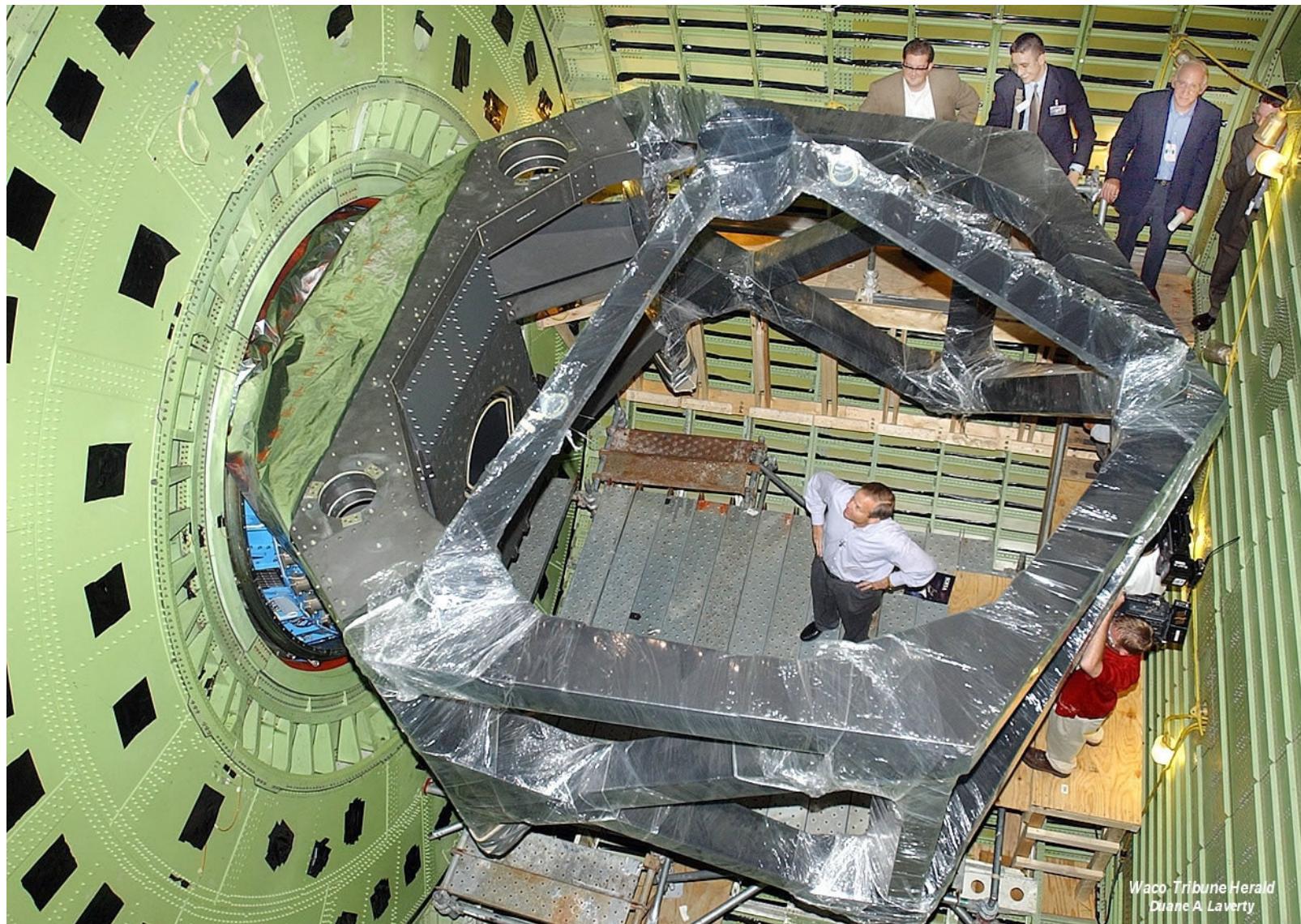


Installing the Telescope Metering Structure

-Waco May 2003



Representative Chet Edwards - June 2003



*Waco Tribune Herald
Duane A Laverty*

Primary Mirror Cell Installation - Waco July 2003

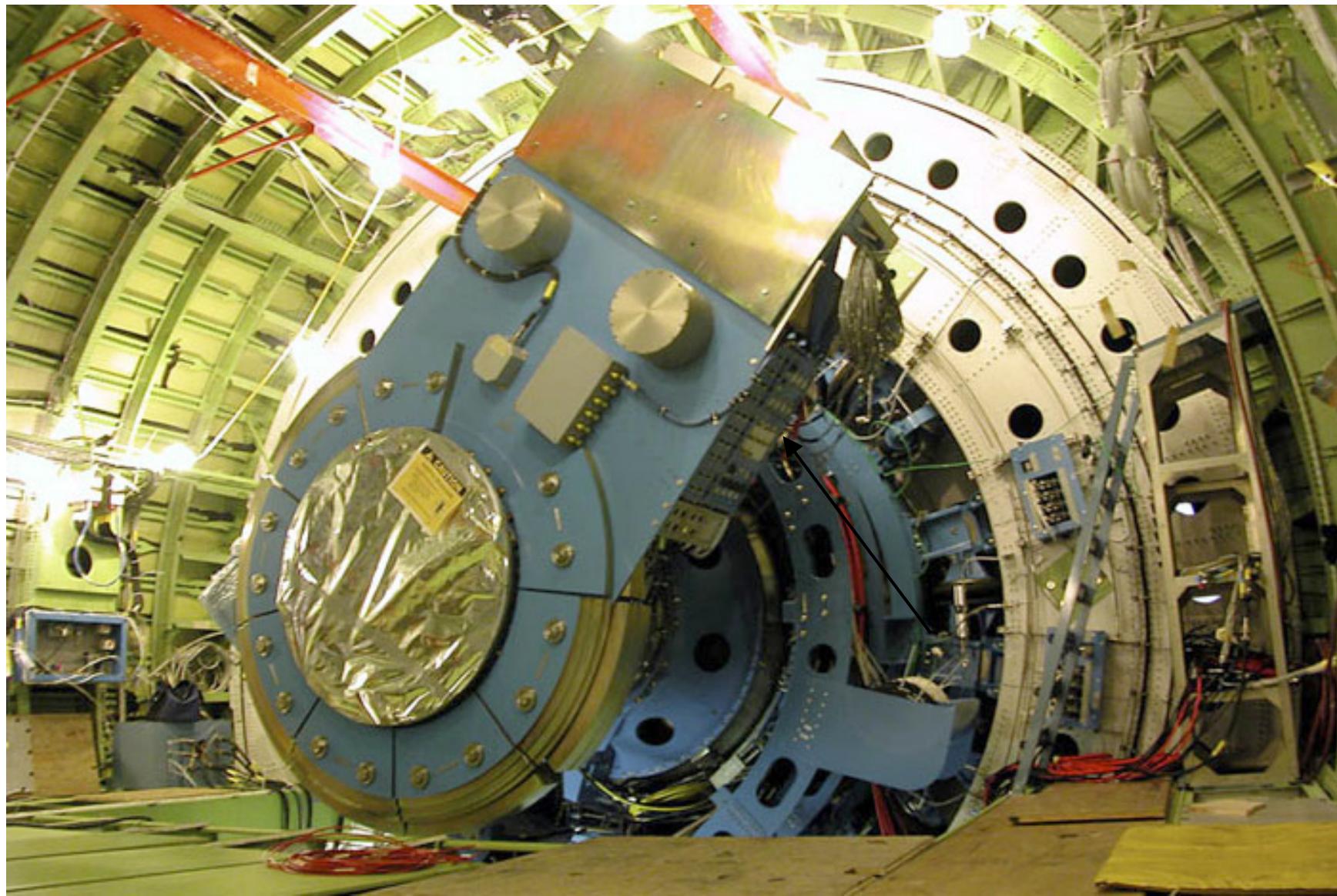


Primary Mirror - France 2002



Science Instrument Mounting Flange Installation - April 2003

Cabling - ongoing; Photo ~ September 2003



Clean SOFIA after Pressure Proof Test of the Aircraft Fuselage - Waco April 2004

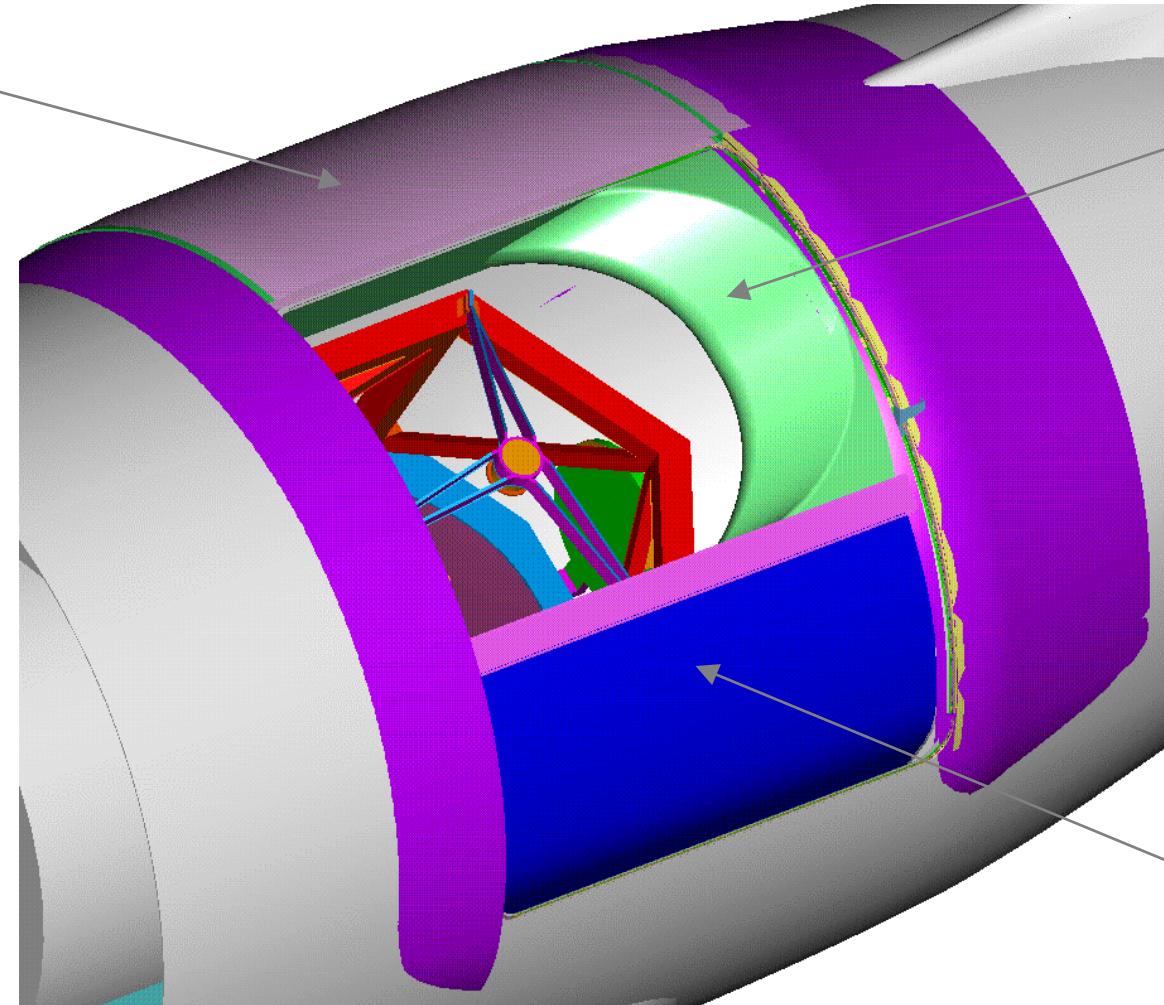


Cavity Door - Being assembled at Ames

Cavity Door

Rigid External
Door

Shear Layer Control

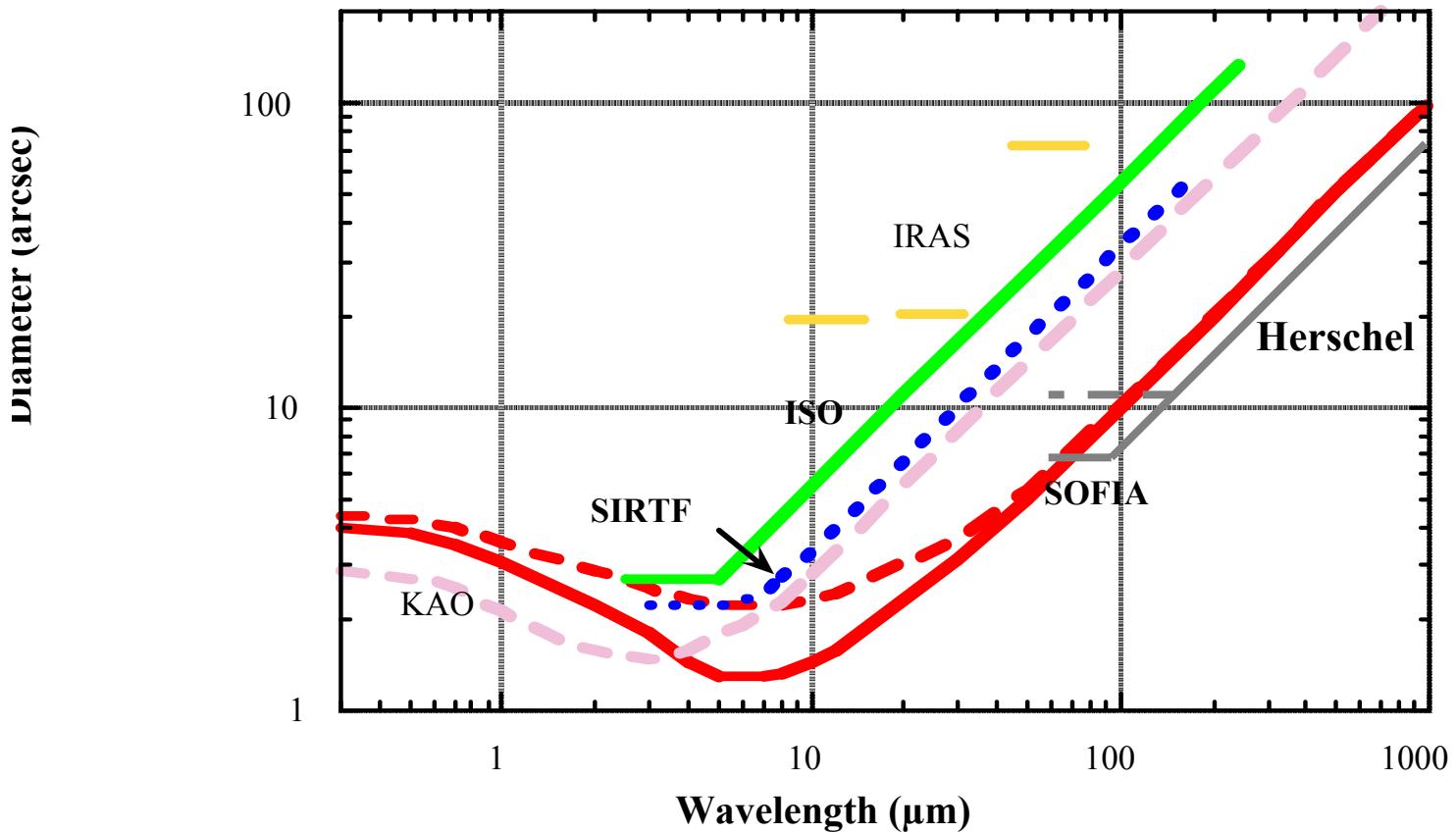


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- ***Operating temperature:*** 240 K
- ***Visible image quality**:** 80% energy within 5.3 arcseconds (first year)
80% energy within 1.6 arcseconds (by third year)

* Includes the effects of pointing jitter but not shear-layer seeing

Angular Resolution



SOFIA will open a new regime of Far-IR angular resolution

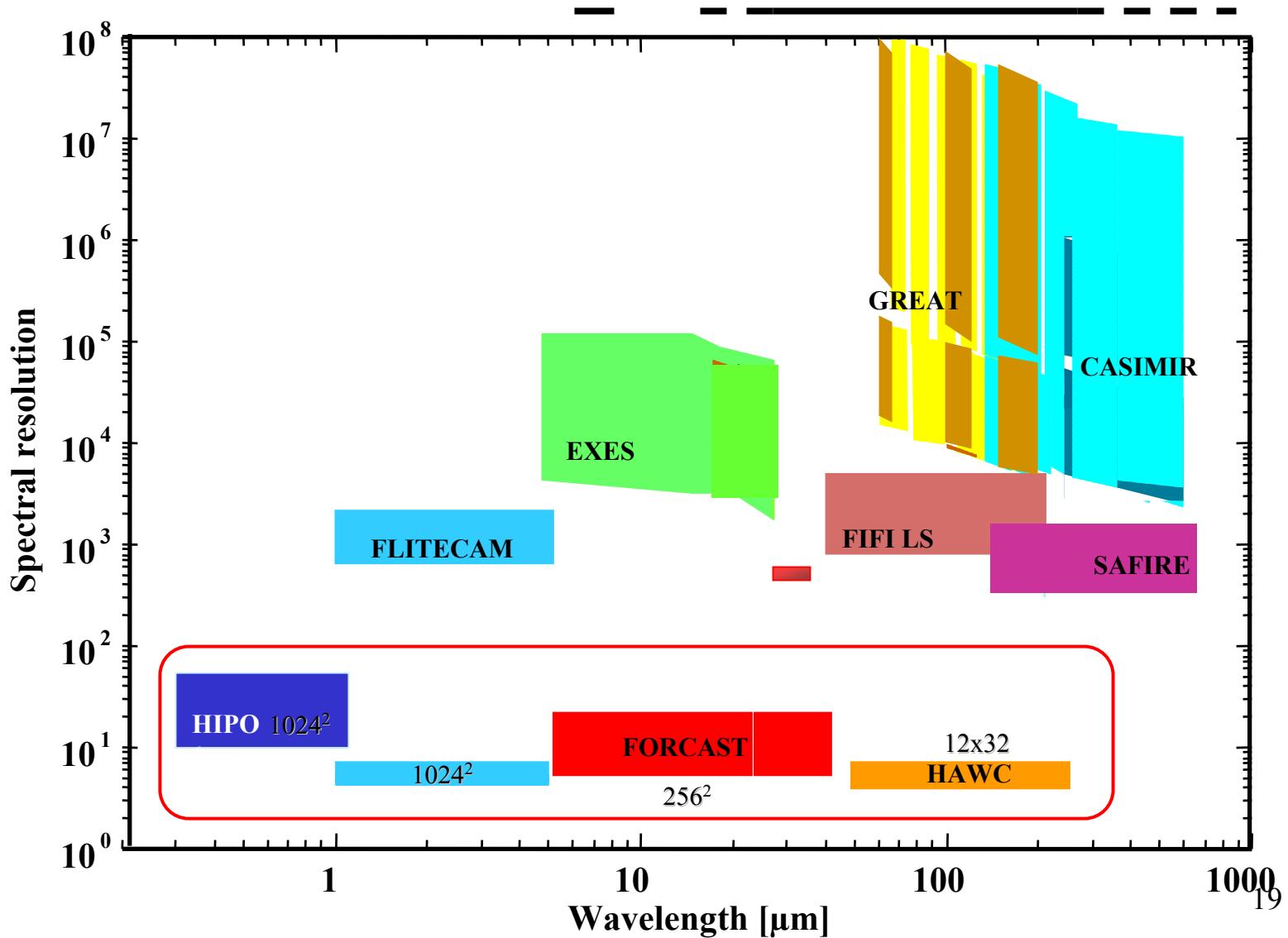
Information on SOFIA Science Instruments:

<http://sofia.arc.nasa.gov>

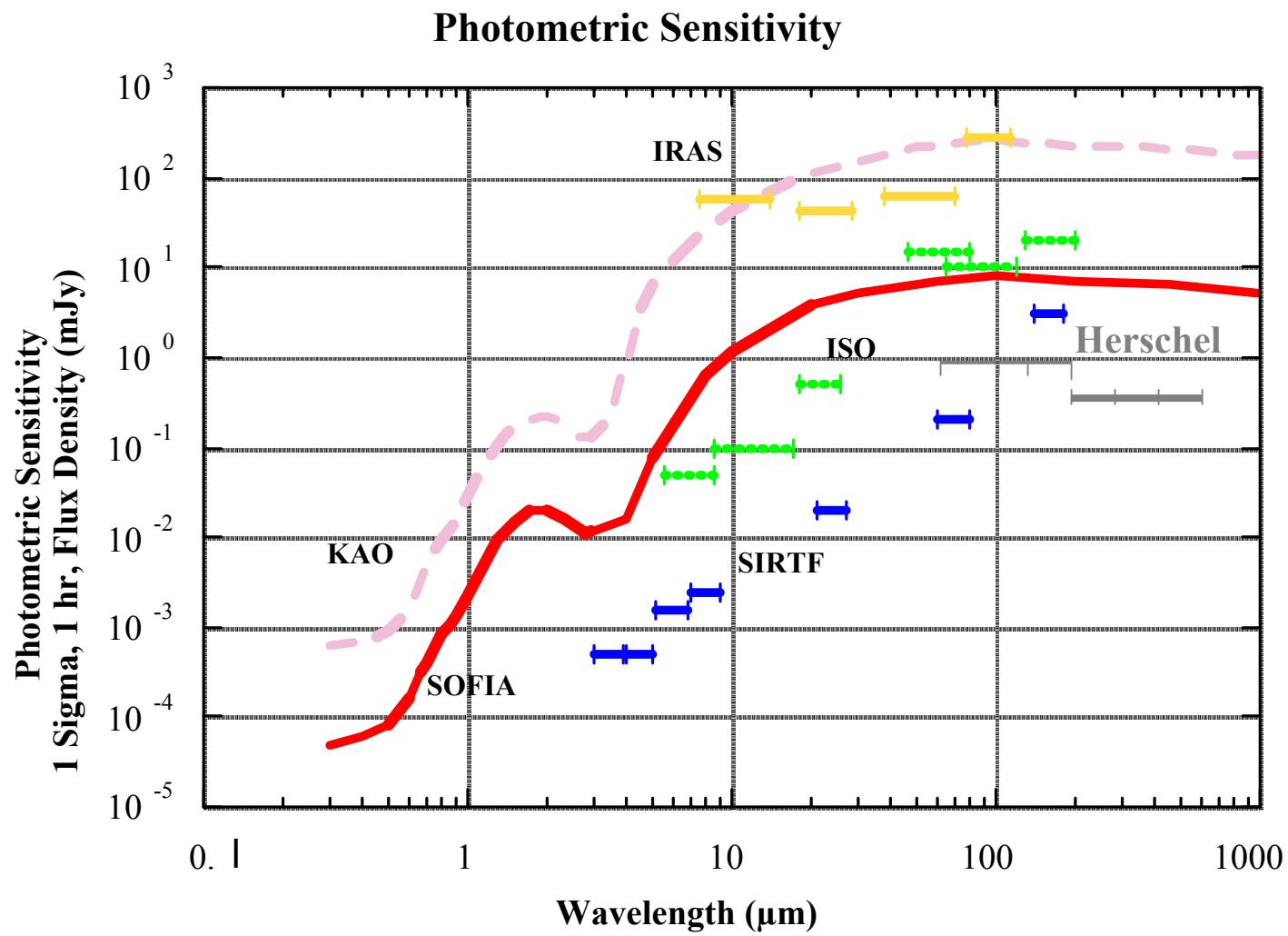
PI	Institution	Name	Type of Instrument	Instrument Class
E. Dunham	Lowell Observatory	HIPO	High-speed Imaging Photometer for Occultations 0.3 – 1.1 microns	Special Class (USA)
I. McLean	UCLA	FLITECAM	Near-IR Test Camera 1 – 5 microns	Facility Class (USA)
J. Lacy	Univ. of Texas	EXES	Echelon Spectrometer 5 – 28 microns; $R = 10^5, 10^4$, or 3000	PI Class (USA)
T. Herter	Cornell	FORCAST	Mid IR Camera 5 – 40 microns	Facility Class (USA)
D.A. Harper	Univ. of Chicago	HAWC	Far Infrared Bolometer Camera 50 – 240 microns	Facility Class (USA)
A. Poglitsch	MPE, Garching	FIFI LS	Field Imaging Far IR Line Spectrometer 40 – 210 microns	PI Class (German)
S. Moseley	NASA-GSFC	SAFIRE	Imaging Fabry-Perot Bolometer Array Spectrometer 145 – 655 microns; $R = 1,000 – 1,900$	PI Class (USA)
R. Guesten	MPIfR, KOSMA, DLR-WS	GREAT	Heterodyne Spectrometer 60 – 200 microns	PI Class (German)
J. Zmuidzinas	Caltech	CASIMIR	Heterodyne Spectrometer 250 – 600 microns	PI Class (USA)

SOFIA First-Light Science Instruments

<http://sofia.arc.nasa.gov>

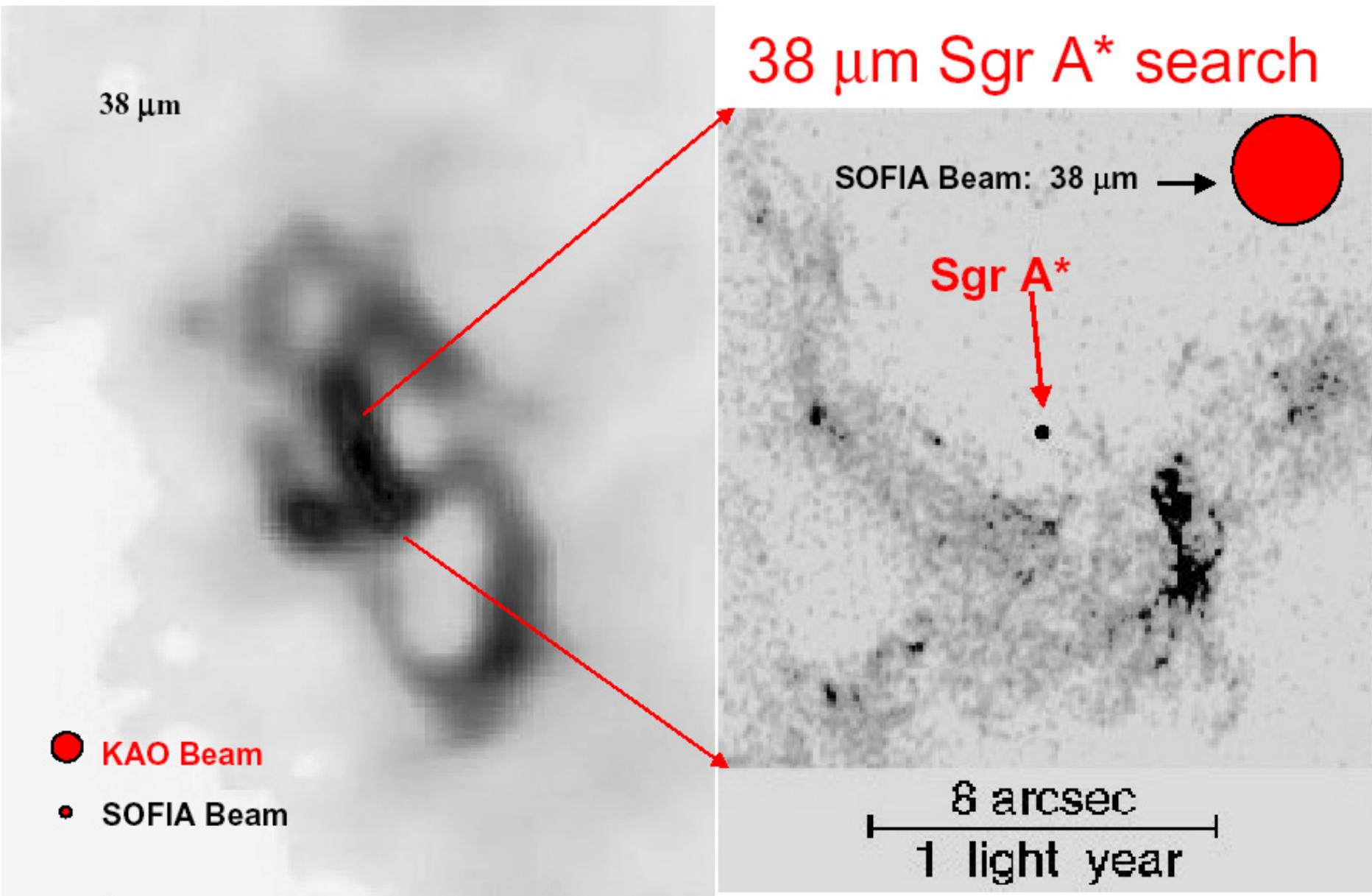


SOFIA Performance:



SOFIA naturally complements Spitzer

- Spitzer observes faint sources only
 - Detectors too sensitive for bright sources
- SOFIA covers the bright sources
 - With good spatial resolution
 - With great spectral resolution
 - i.e., matched to the object being observed



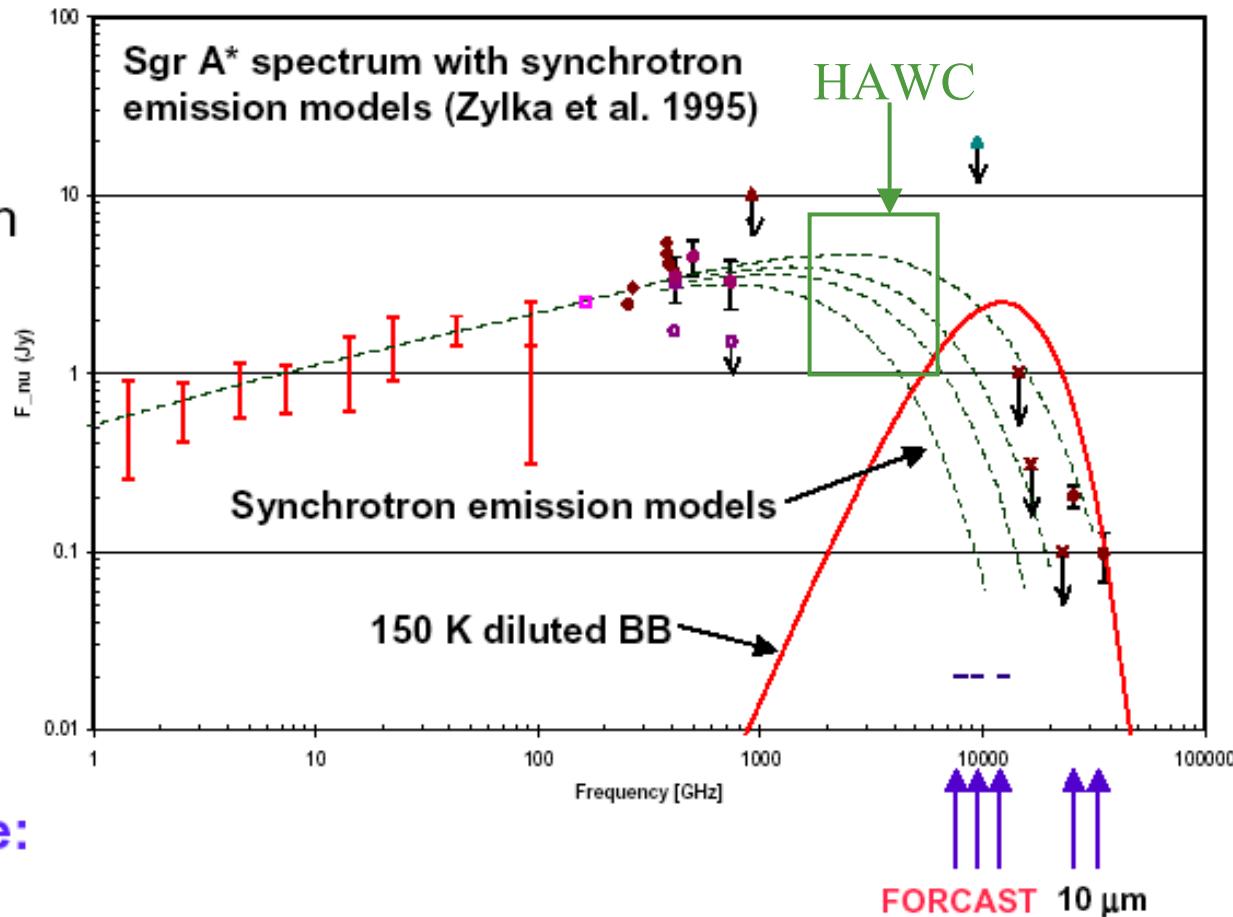
KWIC/KAO Latvakoski et al. 1999

Sgr A* Accretion Disk Models

Mid-IR observations are critical -- strongly constrain accretion disk models

- Highest Energies of Electrons
- Dust Component in Disk

This has proven to be very challenging!



Sensitivity is not an issue:

Spatial resolution is the issue –

separate nearby dust emission from streamers and ring.

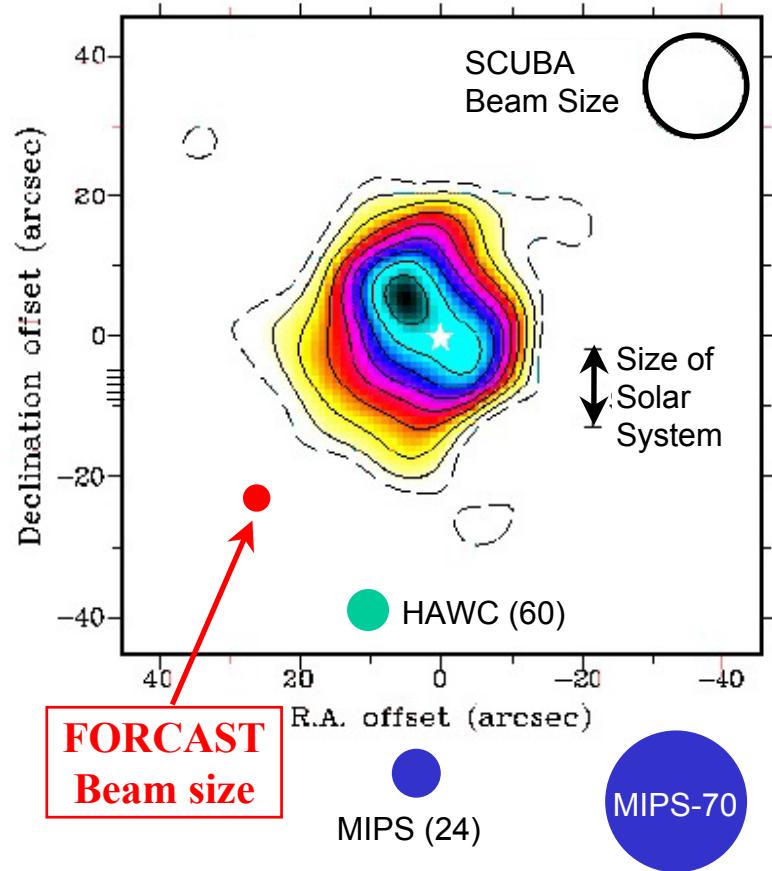
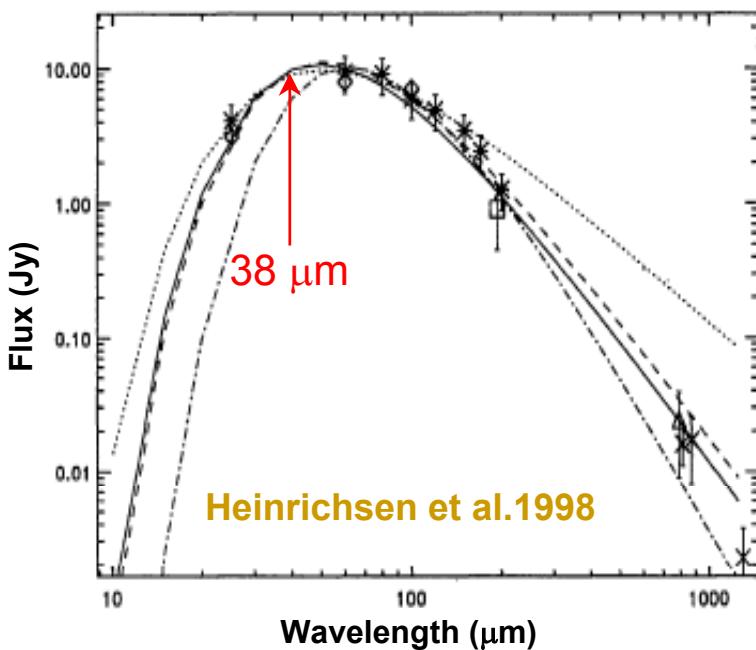
Circumstellar Disks: Vega

SCUBA 850 μm : $r_{\text{disk}} \sim 20''$ (160AU)

$$\Rightarrow T_{\text{dust}} \sim 80 \text{ K}$$

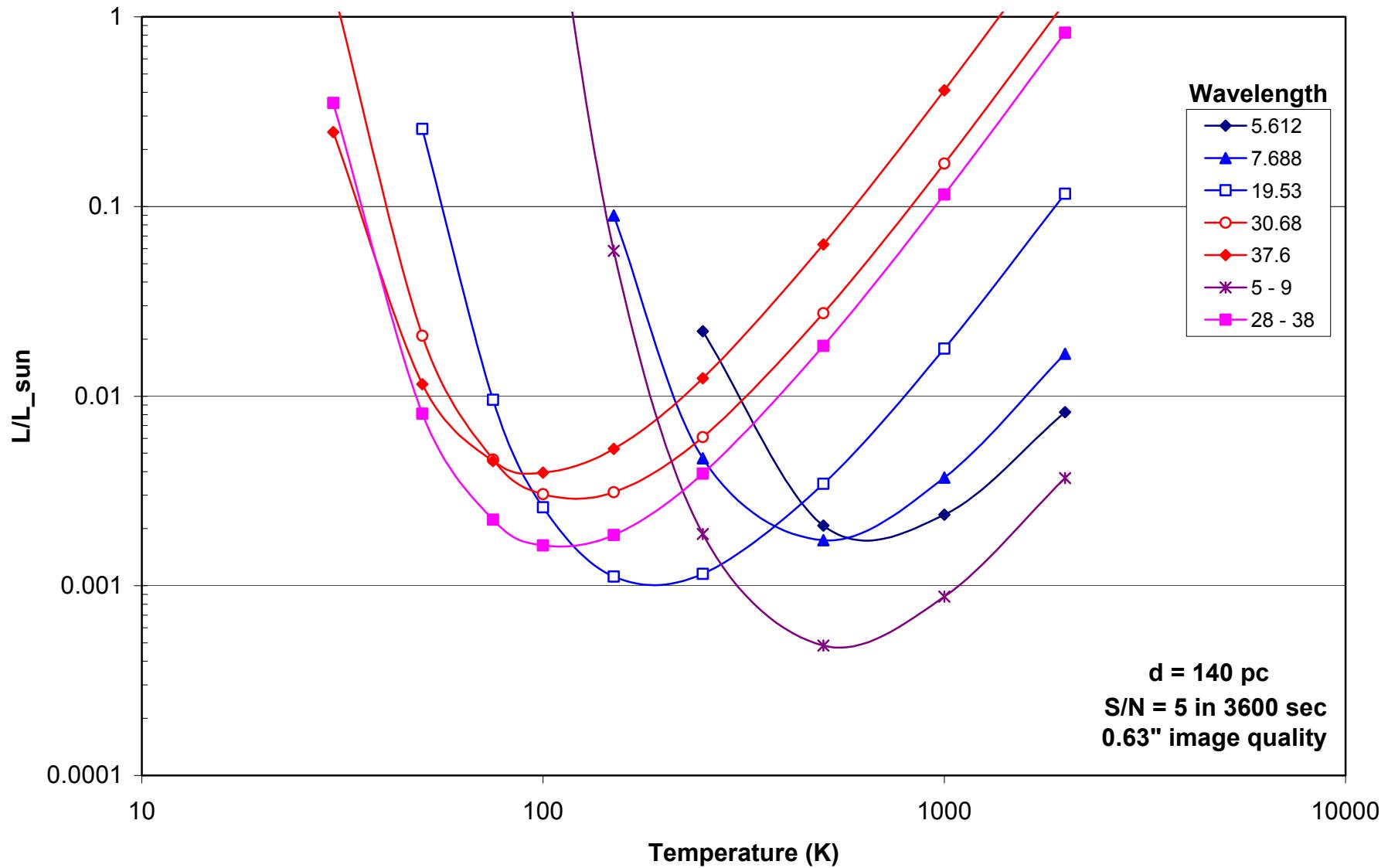
$$\Rightarrow \lambda_{\text{peak}} \sim 35 \mu\text{m}$$

ISO observed $\lambda_{\text{peak}} \sim 35 \mu\text{m} \Rightarrow$
little dust at $r < 160 \text{ AU} \Rightarrow$
hole in distribution

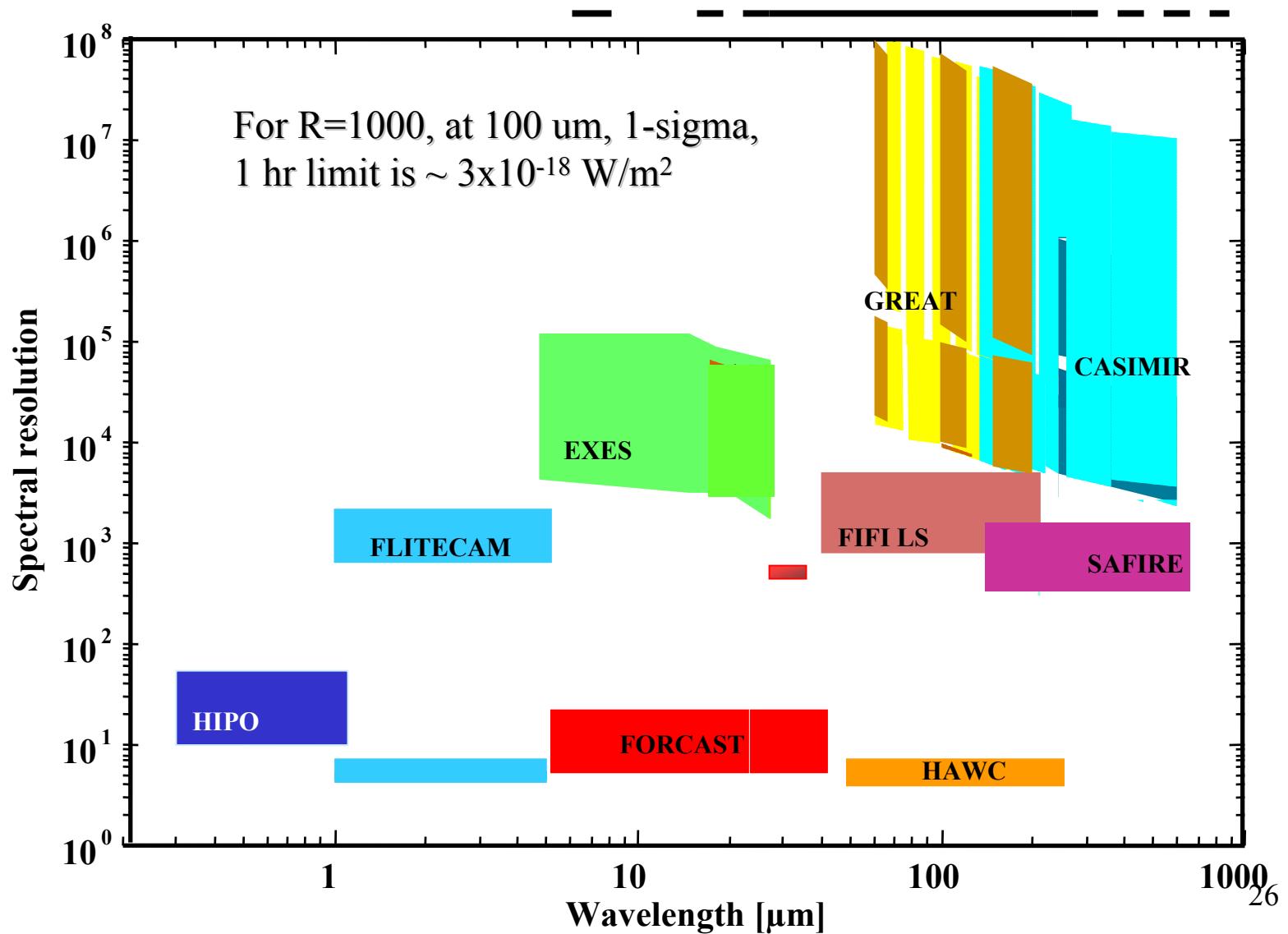


FORCAST: Resolve disk and hole \Rightarrow distribution of dust...
and planets?

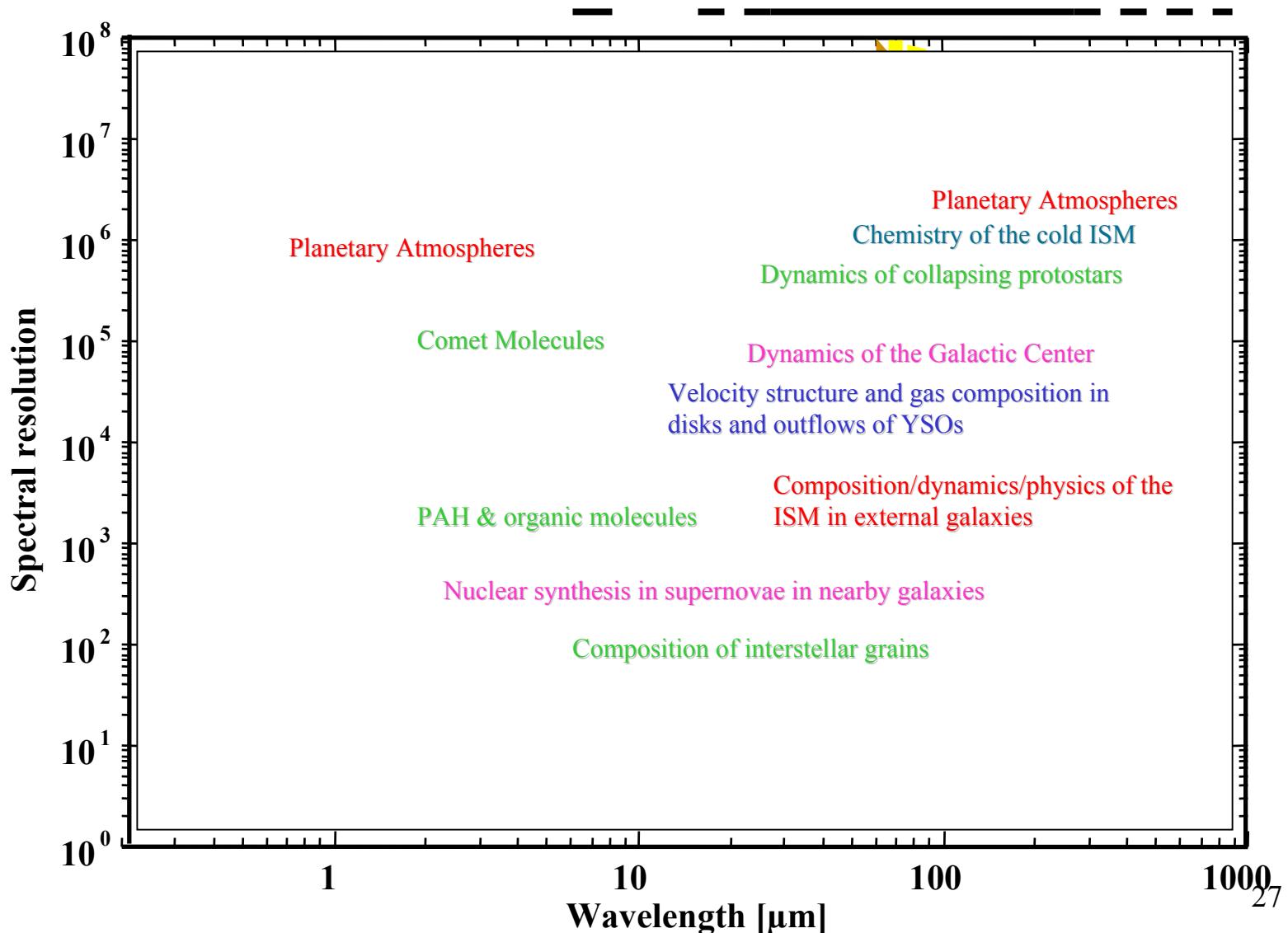
Protostellar/Stellar Detectability with FORCAST



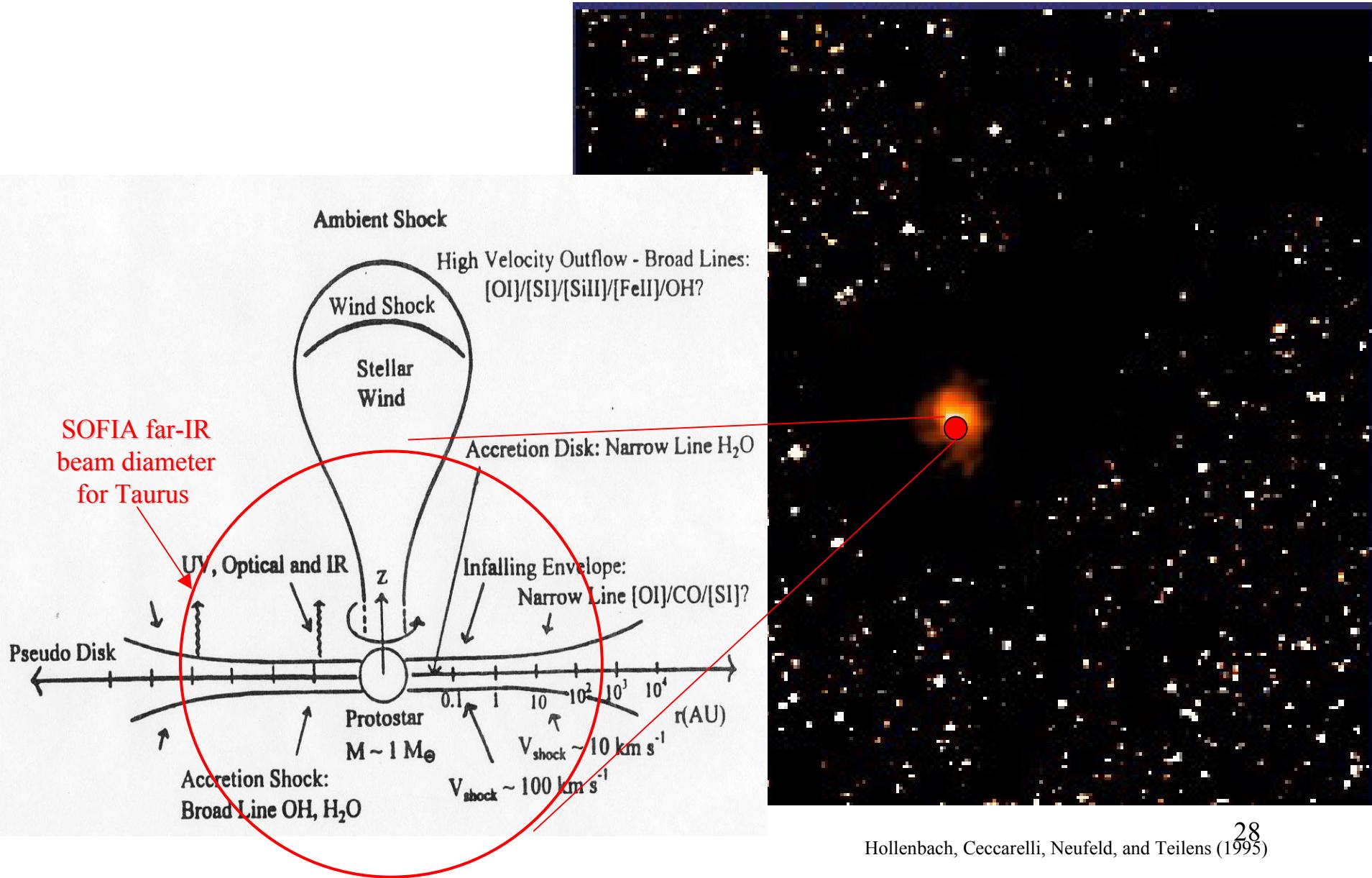
SOFIA First-Light Science Instruments



SOFIA First-Light Science Instruments



Low-Mass Star Formation



GREAT - CO(J>13) lines in inner most regions of circumstellar envelopes

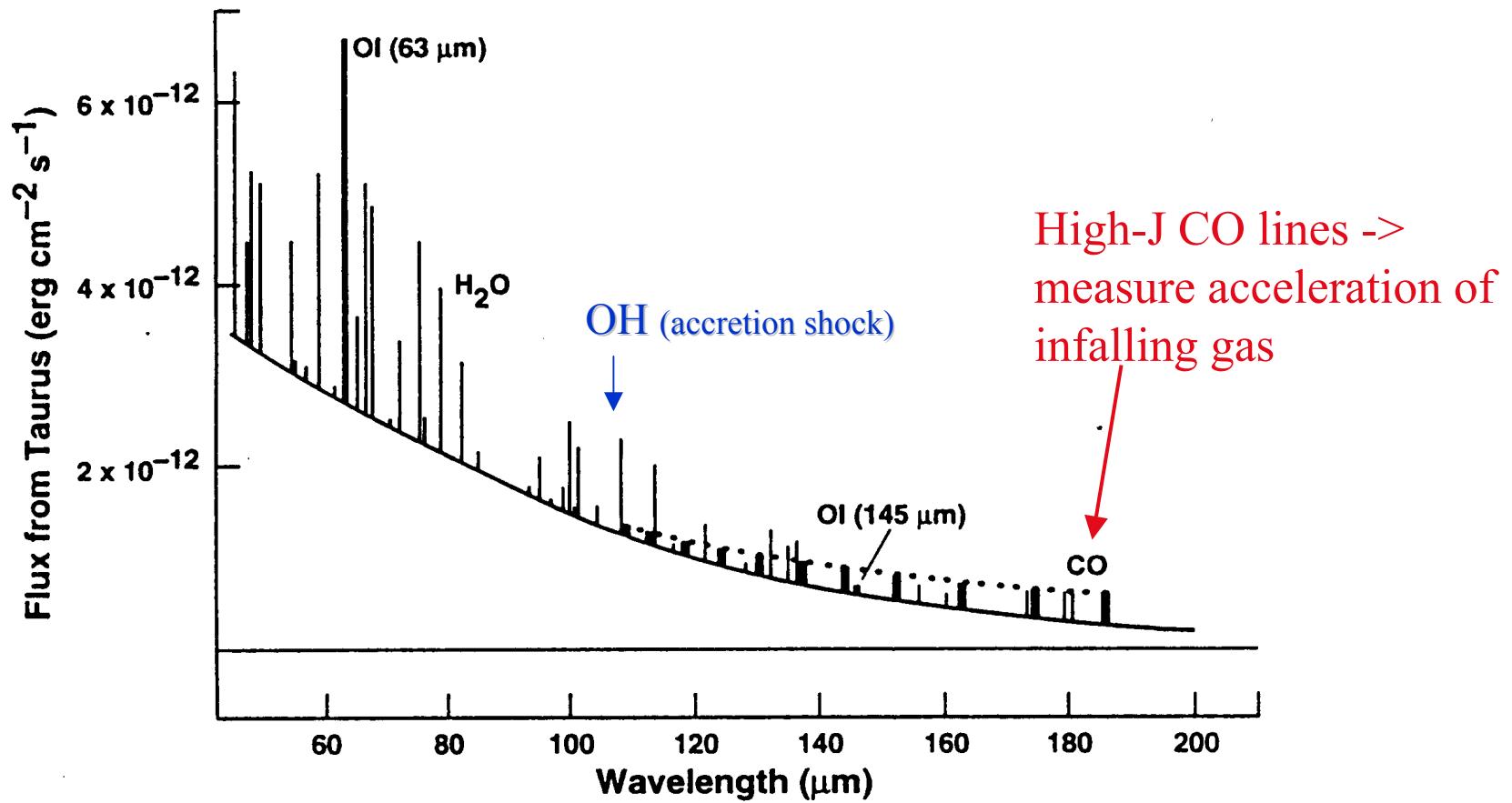
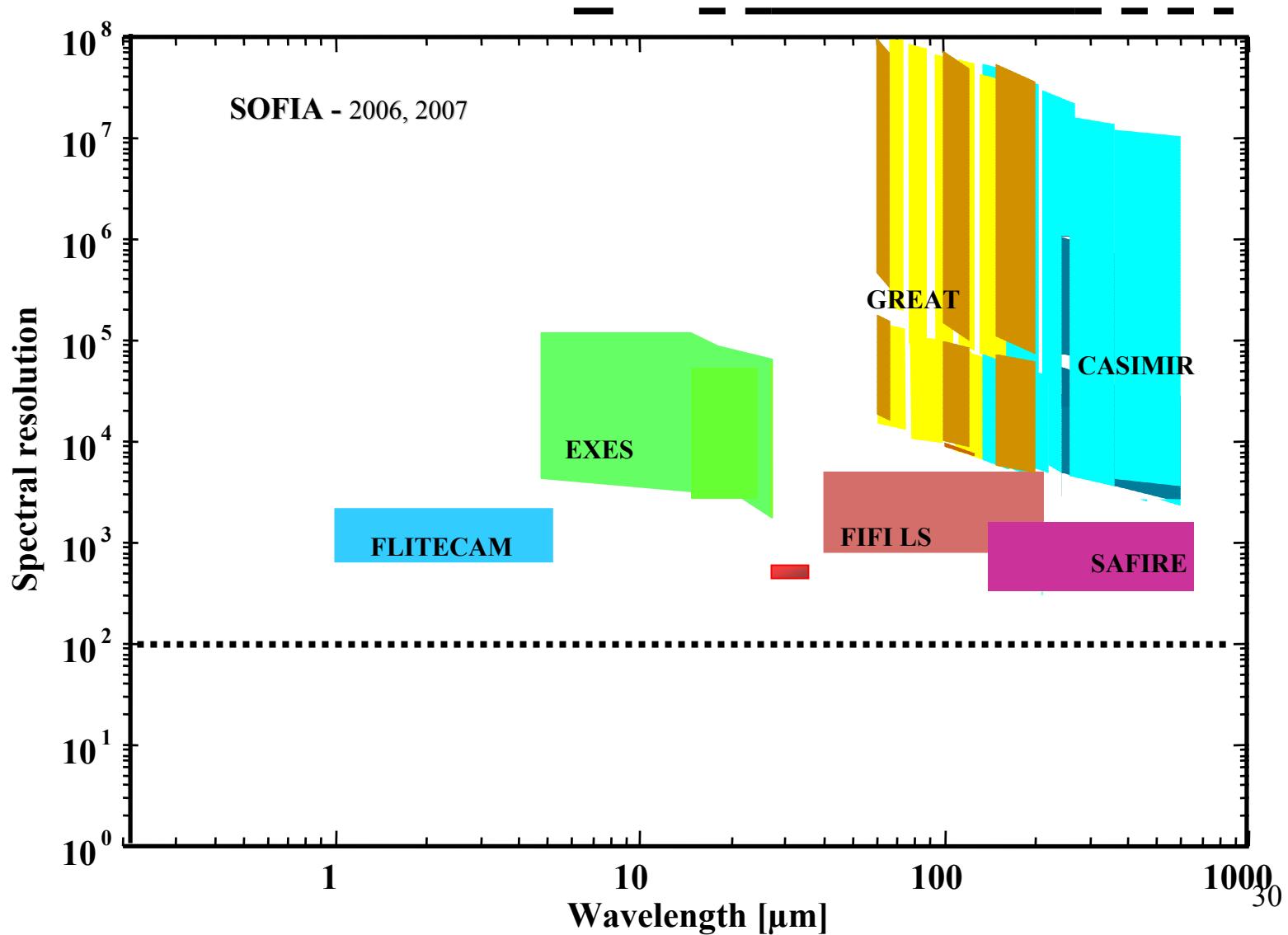
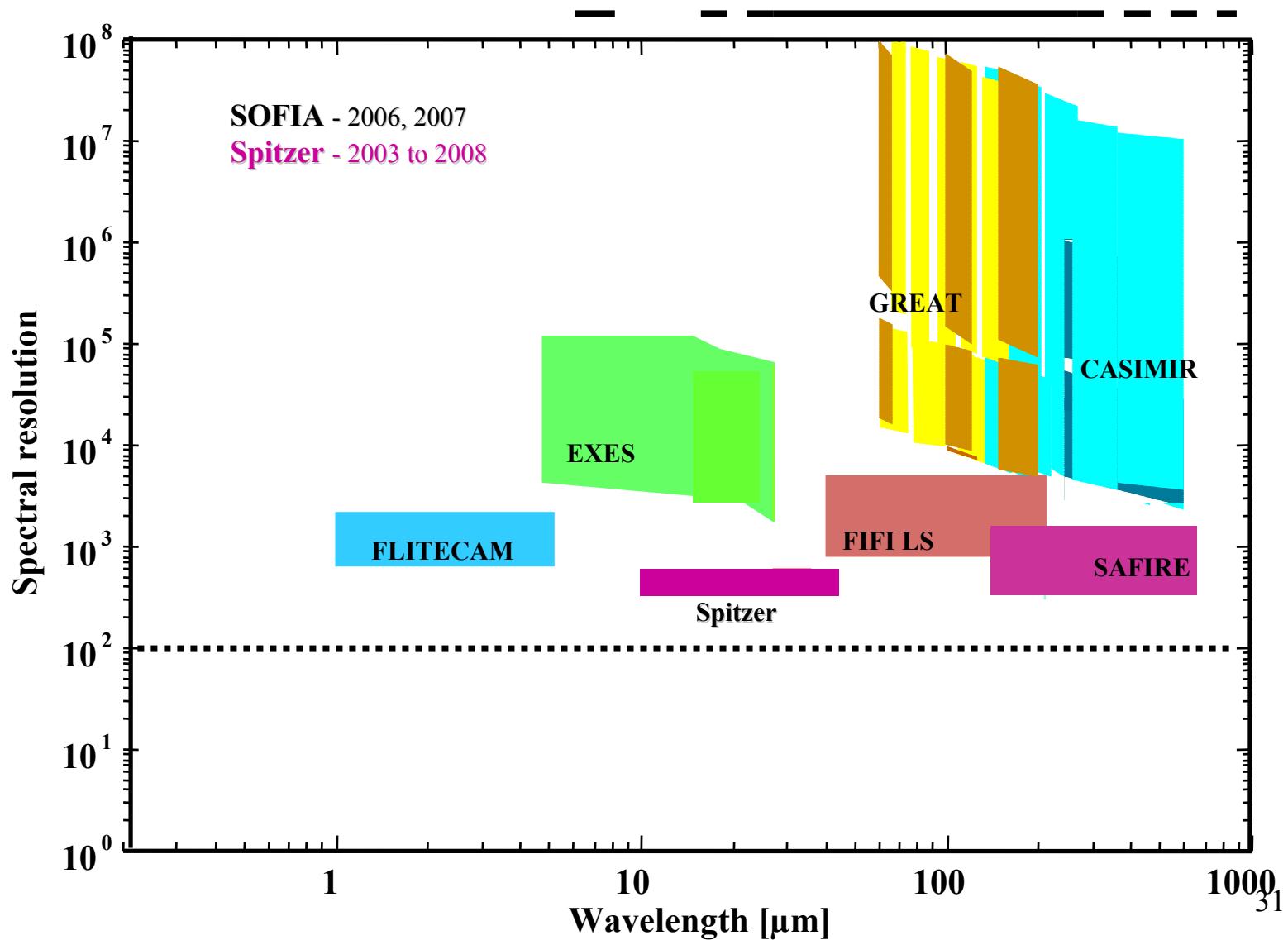


Figure 1. Freefall spectrum of 1 M_\odot protostar in Taurus ($R = \lambda / \Delta\lambda \sim 10^4$) $\dot{M}_{\text{rate}} = 10^{-5} \text{ M}_\odot / \text{yr}$

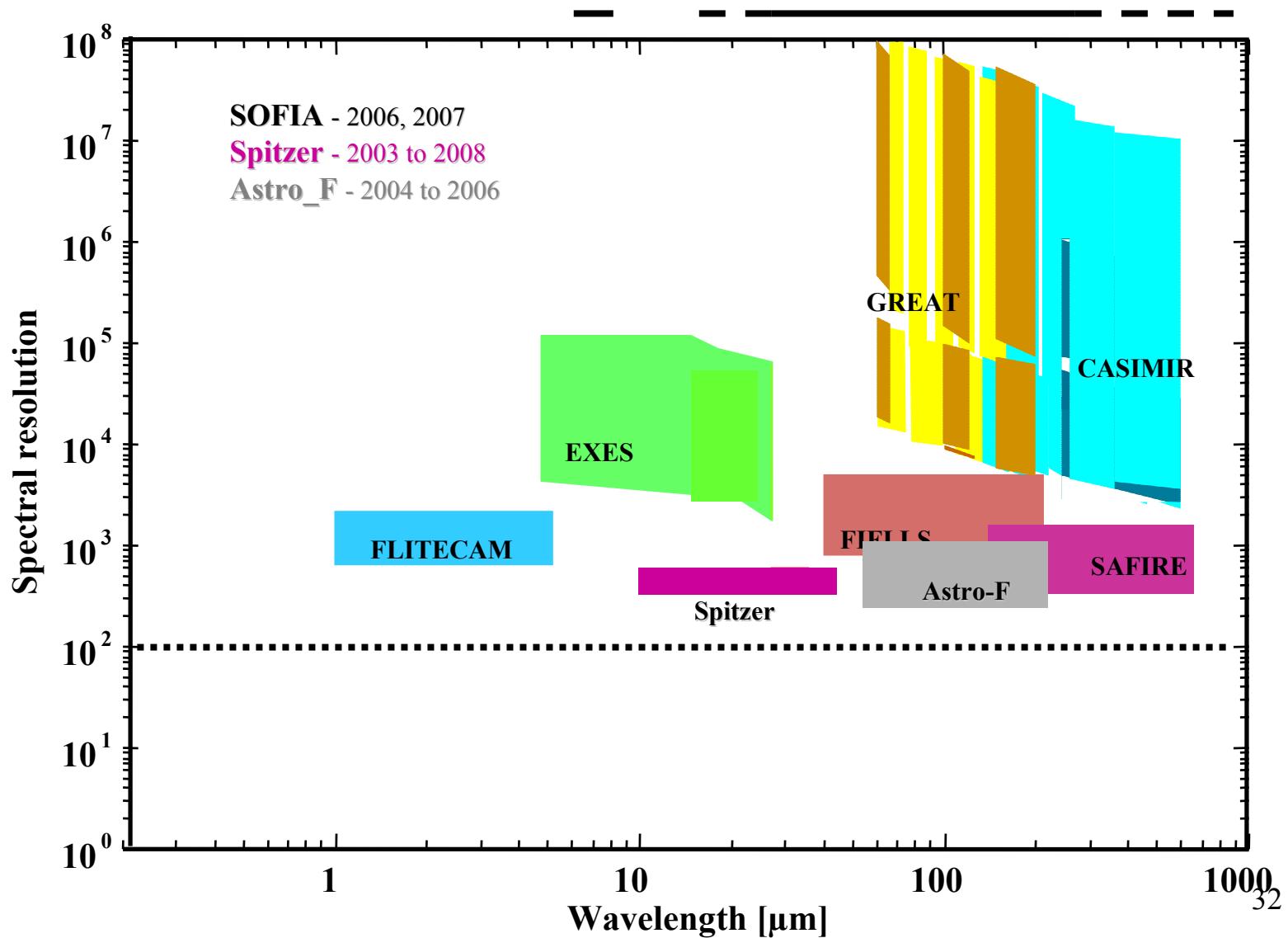
Spectroscopic Capabilities, 2003 - 2025



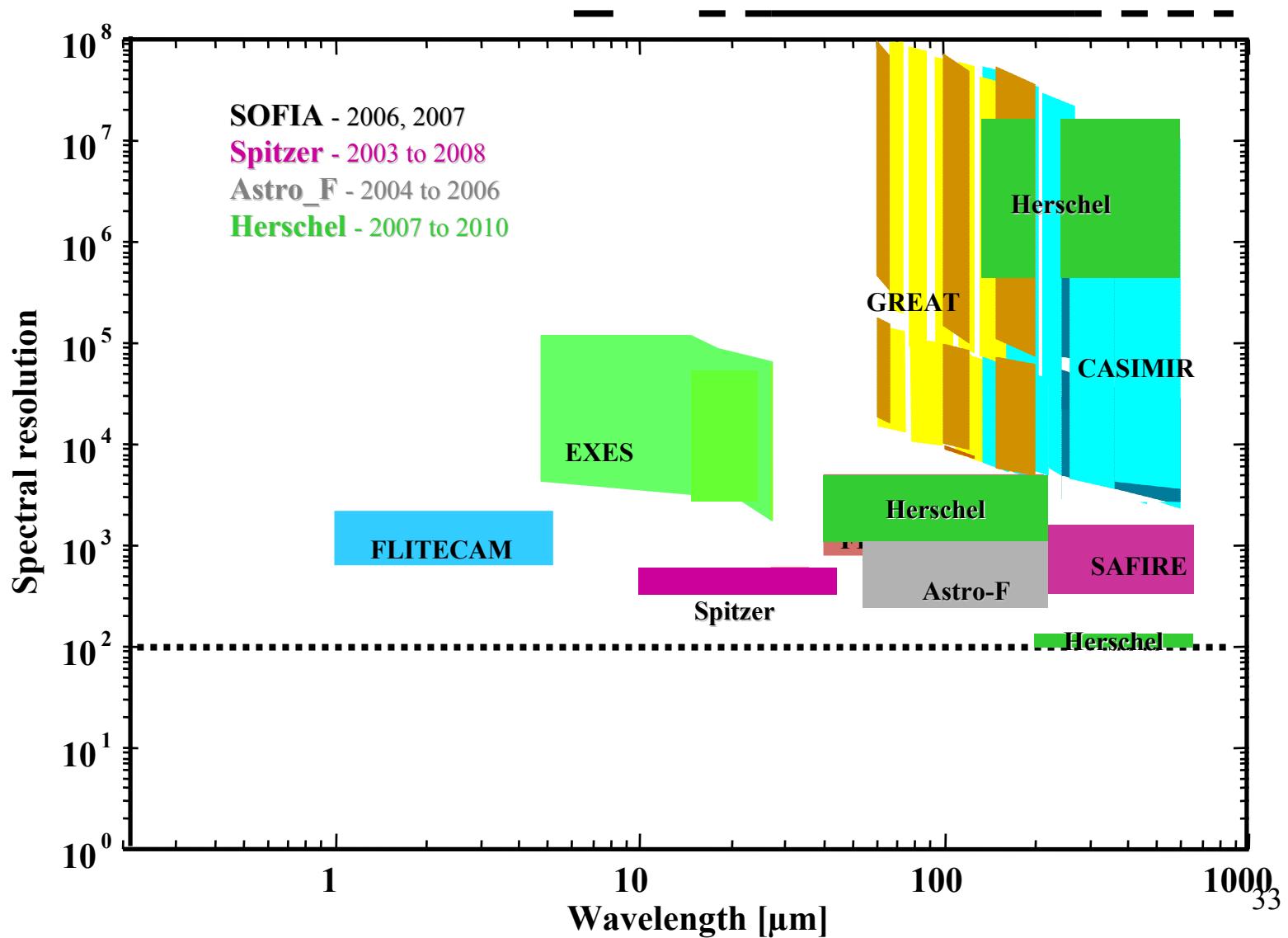
Spectroscopic Capabilities, 2003 - 2025



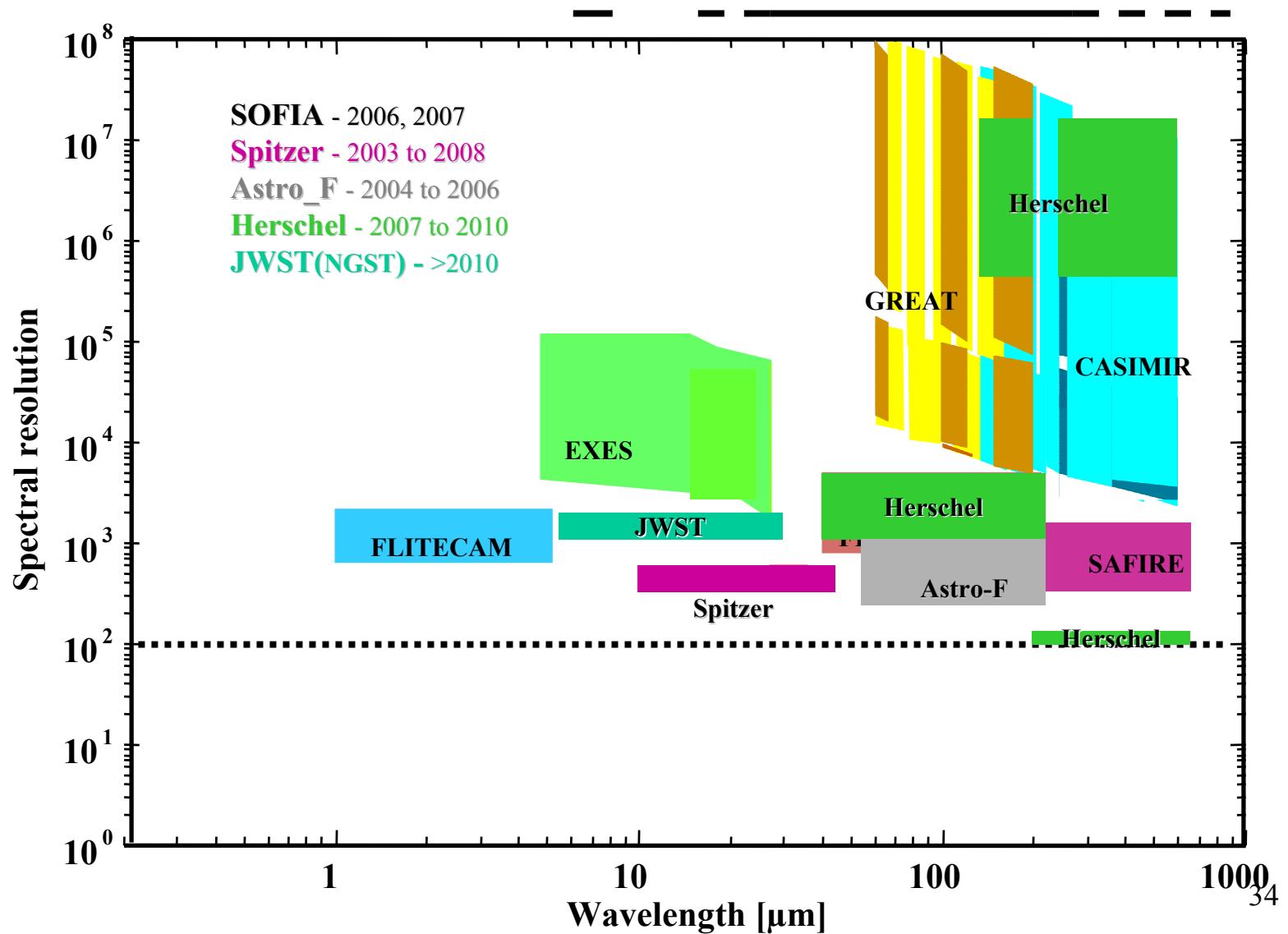
Spectroscopic Capabilities, 2003 - 2025



Spectroscopic Capabilities, 2003 - 2025



Spectroscopic Capabilities, 2003 - 2025



SOFIA complements Herschel

- Herschel can't do the whole sky in three years!
 - Must be selective
- Herschel is a natural for surveys
 - especially of faint sources (e.g., distant galaxy)

Blank Field Surveys

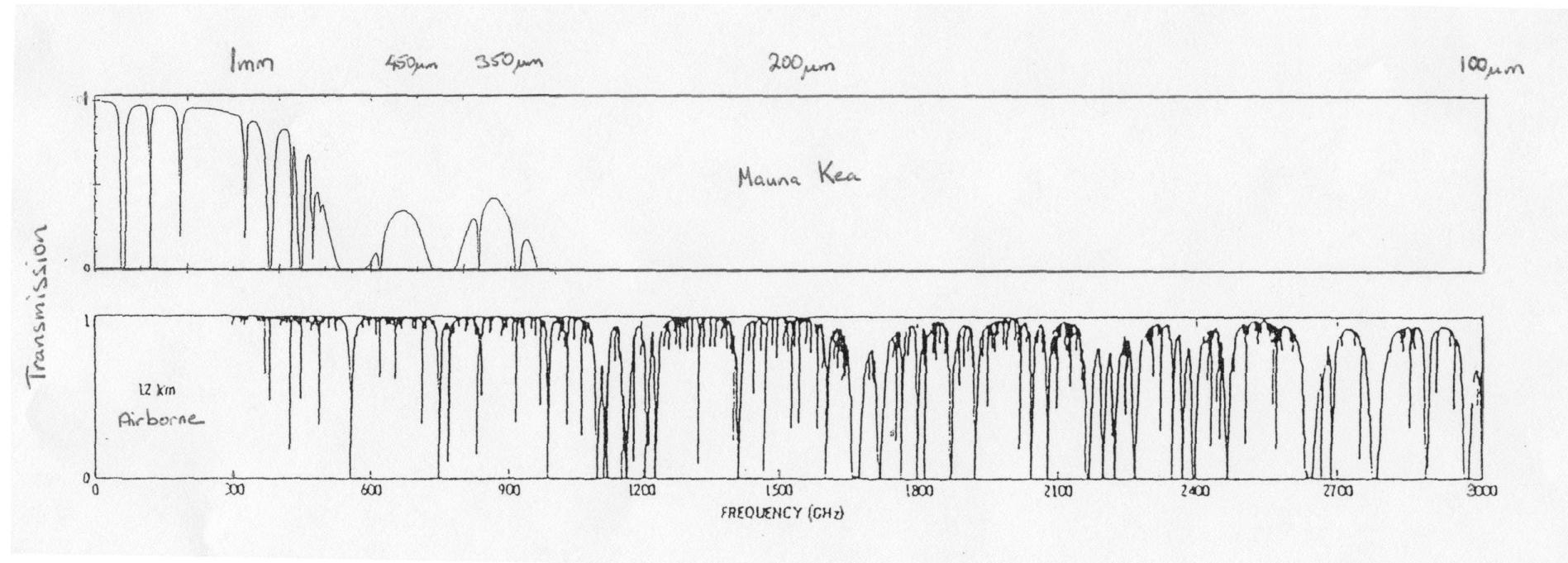
Facility	λ (μm)	galaxies/hour (5σ)
SCUBA/JCMT	850	0.2
MAMBO/IRAM	1300	0.3
SHARC II/CSO	350	0.1
HAWC/SOFIA (2005)	200	3
Spitzer (2004)	≤ 160	100
Herschel (2007)	170-500	100

A. Blain

SOFIA complements Herschel

- Herschel is a natural for lines obscured by Earth's atmosphere above the tropopause

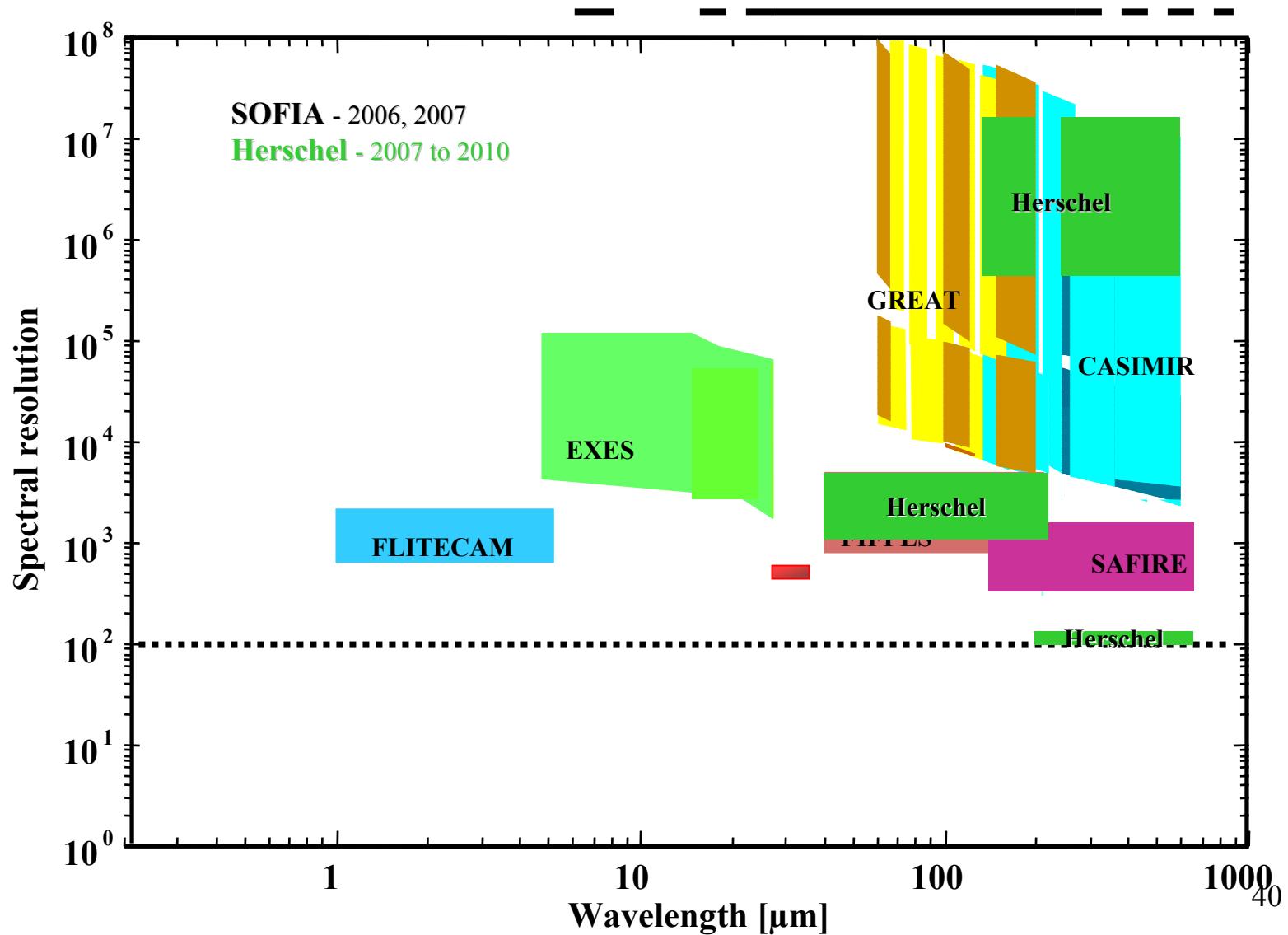
Sub-mm on SOFIA



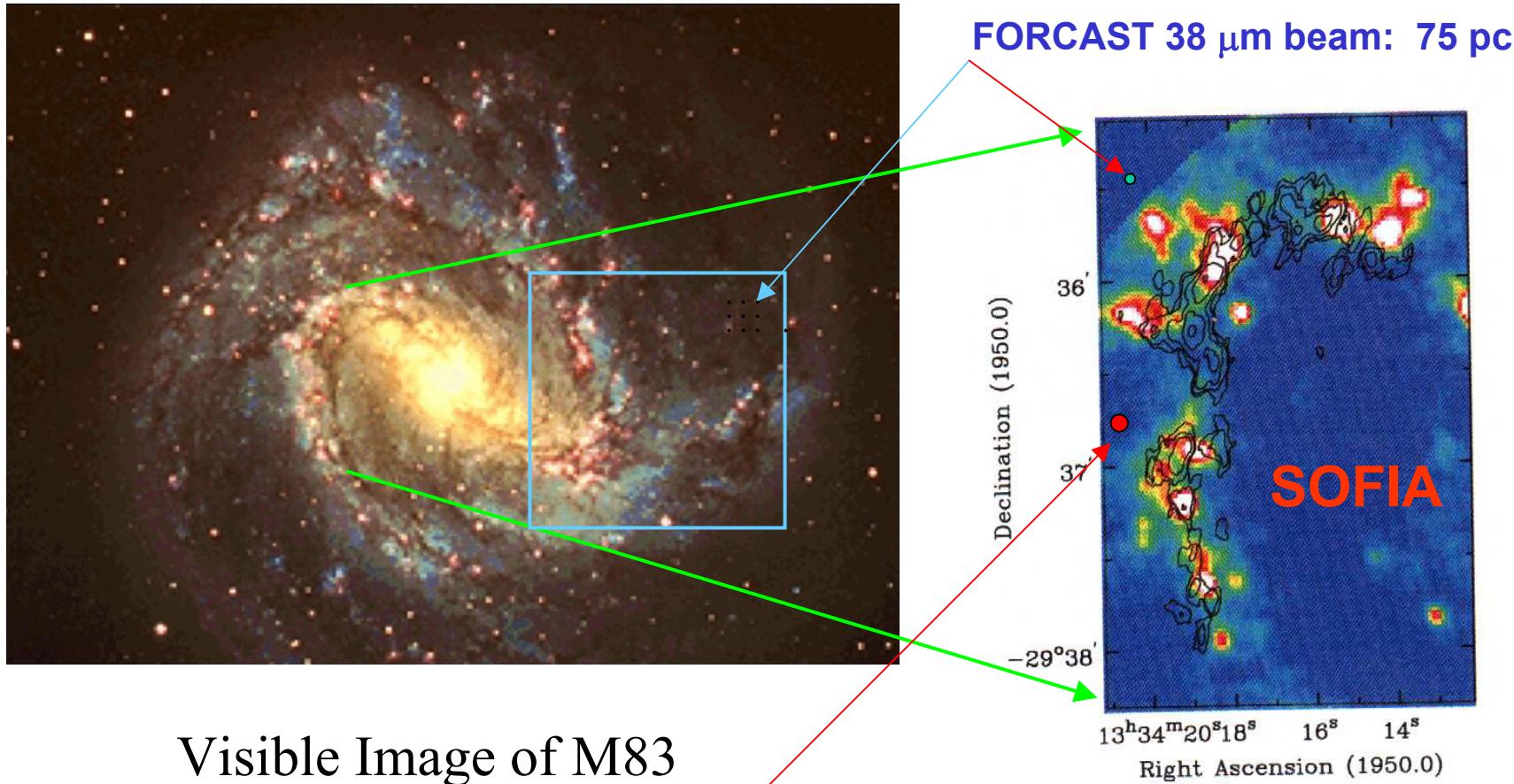
SOFIA complements Herschel

- **SOFIA is a natural for in-depth studies of particular targets**
 - With **increased** spectral coverage
 - With **increased** science instrument capabilities

Spectroscopic Capabilities



Nearby Face-on Spiral Galaxies: M83



Visible Image of M83

6'' Resolution CO (1-0) Map
overlaid on false-color HI (Rand,
Lord, & Higdon 1999)

SOFIA (& Herschel) will resolve Far-IR Lines and Far-IR continuum Emission from
Spiral Arms \Leftrightarrow Star Formation and Spiral Density Waves

Far-IR Spectral Lines

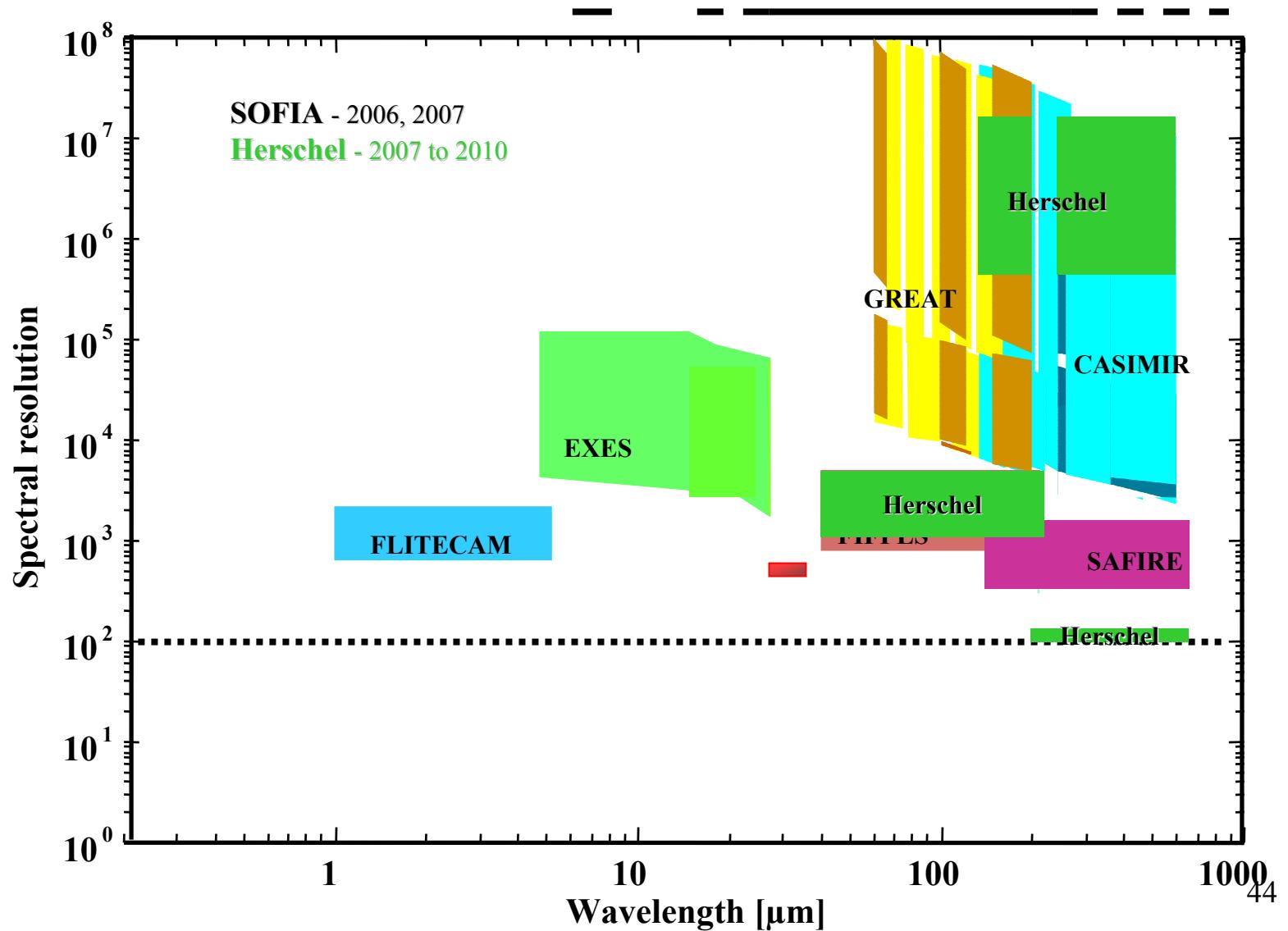
- A host of Far-IR fine-structure and molecular-transition lines, accessible to SOFIA at optimum spectral resolutions, can probe the physical properties of the ISM of the Milky Way and other galaxies:
 - [OI]*, [SiII] lines probe the physical conditions of gas in PDRs.
 - [NIII], [SIII], and [OIII]* line pairs are excellent probes of HII region densities.
 - [NII]* lines trace the warm ionized medium.
 - [CII]* line traces PDRs, atomic clouds, and warm ionized medium.
 - [NII]*/[NIII], [SIII]/[OIII]*, [NeIII]/[OIV]/[NeV] ratios give the effective temperature of stellar or AGN UV radiation fields.
 - [SI], [SiI]*, [SiII] and [FeI] lines indicate the presence of dissociative J-shocks.
 - High J CO* rotational lines trace shocked gas found in warm dense gas of PDRs.
 - OH* lines trace shocked gas in cool dense gas.
 - H₂ rotational lines probe the mass of warm molecular clouds.
 - OH*, CH*, and NH₃* together constrain molecular cloud chemistry.
- Lines with “*” are observable from Herschel as well. **Herschel** cannot observe all of the **SOFIA** lines.

Table I. Selected fine structure lines arising in ionized regions

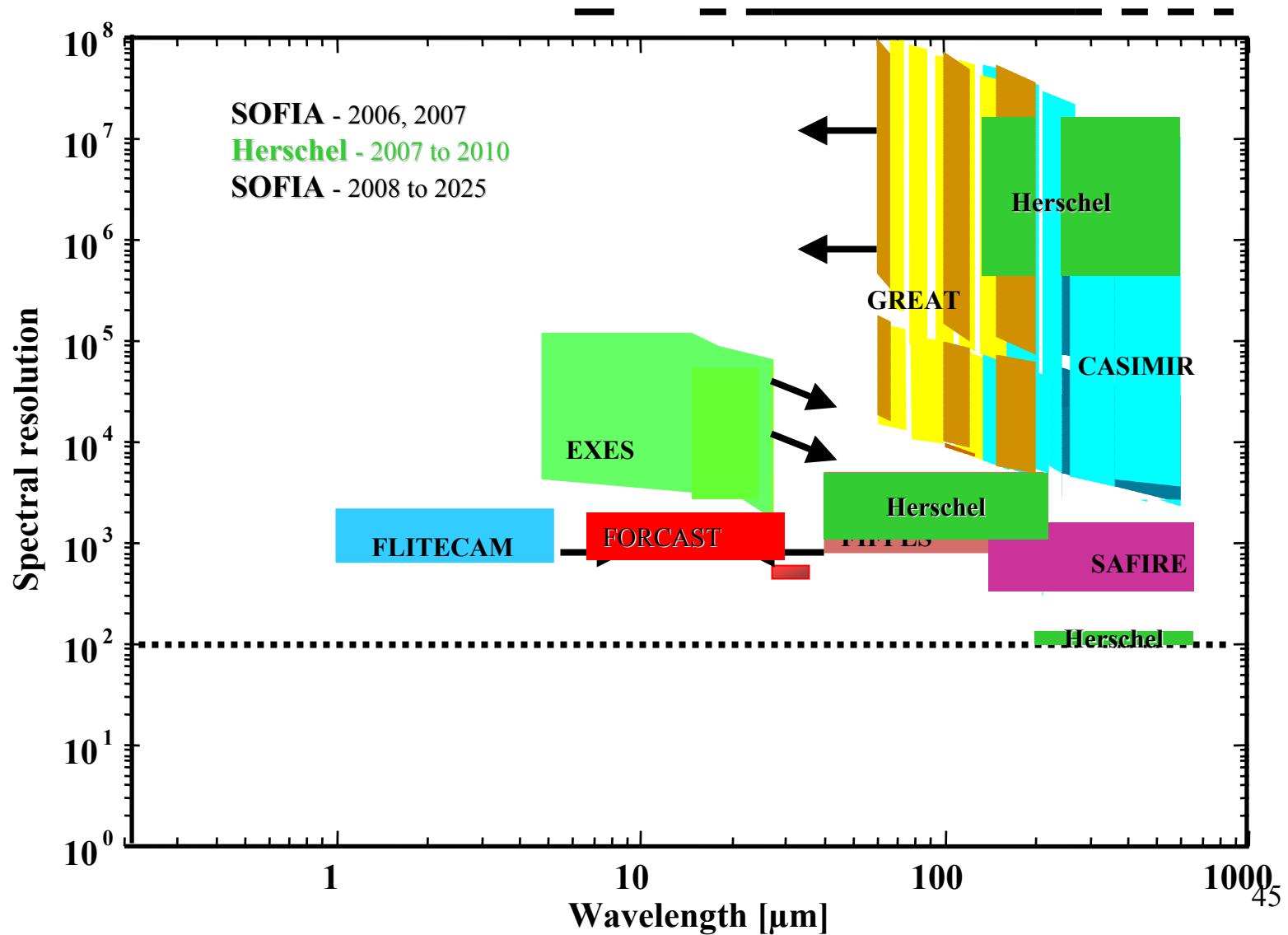
Transition	Species	λ (μm)	A (s^{-1}) [28]	n_{cr} (cm^{-3}) (a)	Excitation Range (eV) [29]
$2p : ^2P_{3/2} \rightarrow ^2P_{1/2}$	N^{++}	57.317	4.77×10^{-5}	3.0×10^3	29.6–47.4
	O^{+++}	25.87	5.18×10^{-4}	1.0×10^4	54.9–77.4
$3p : ^2P_{3/2} \rightarrow ^2P_{1/2}$	S^{+++}	10.51	7.70×10^{-3}	5.6×10^4	34.8–47.3
$2p^2 : ^3P_1 \rightarrow ^3P_0$	N^+	203.9	2.13×10^{-6}	4.8×10^1	14.5–29.6
$^3P_2 \rightarrow ^3P_1$		121.889	7.48×10^{-6}	3.1×10^2	
	O^{++}	88.355	2.62×10^{-5}	5.1×10^2	35.1–54.9
		51.816	9.75×10^{-5}	3.6×10^3	
	Ne^{++++}	24.28	1.28×10^{-3}	5.4×10^4	97.1–126
		14.33	4.59×10^{-3}	3.8×10^5	
$3p^2 : ^3P_1 \rightarrow ^3P_0$	S^{++}	33.443	4.72×10^{-4}	2.0×10^3	23.3–34.8
$^3P_2 \rightarrow ^3P_1$		18.713	2.07×10^{-3}	1.7×10^4	
$2p^4 : ^3P_1 \rightarrow ^3P_2$	Ne^{++}	15.56	5.99×10^{-3}	2.9×10^5	41.0–63.5
$^3P_0 \rightarrow ^3P_1$		36.02	1.15×10^{-3}	4.2×10^4	
$3p^4 : ^3P_1 \rightarrow ^3P_2$	Ar^{++}	8.9912	3.08×10^{-2}	3.1×10^5	27.6–40.7
$^3P_0 \rightarrow ^3P_1$		21.83	5.19×10^{-3}	3.5×10^4	
$2p^5 : ^2P_{1/2} \rightarrow ^2P_{3/2}$	Ne^+	12.813	8.59×10^{-3}	5.4×10^5	21.6–41.0
$3p^5 : ^2P_{1/2} \rightarrow ^2P_{3/2}$	Ar^+	6.99	5.26×10^{-2}	1.9×10^6	15.8–27.6

Watson 1985

Spectroscopic Capabilities



Spectroscopic Capabilities



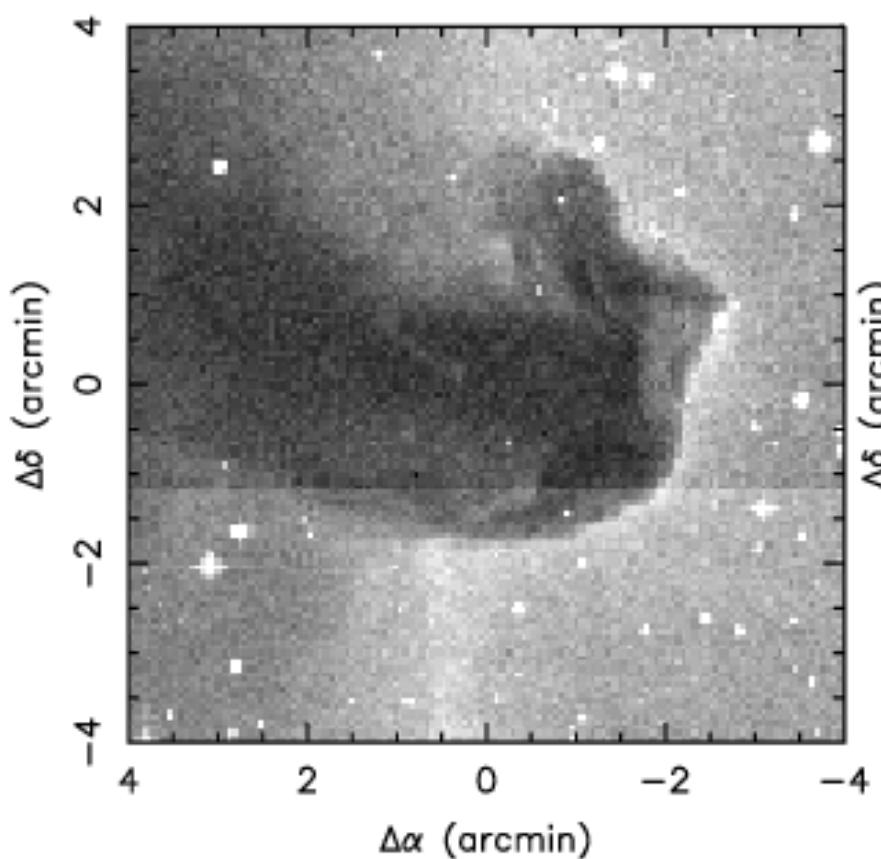
Increasing High Resolution Spectral Capabilities on SOFIA

- Finish SAFIRE (TES array, Fabry-Perot Spectrometer)
- EXES (Echelon Spectrometer)
 - Increase detector array size from 256^2 to 1024^2 Si:As array
- FORCAST (mid-IR camera)
 - Add Grism to allow for R=2,000 spectroscopy
- GREAT & CASIMIR (heterodyne spectrometers)
 - HEB mixers and new type of LOs for coverage <200 um
 - Heterodyne arrays
- Develop R $\sim 10^4$ - 10^5 spectral resolving capability spanning from 40 um to 200 um in one spectrometer.

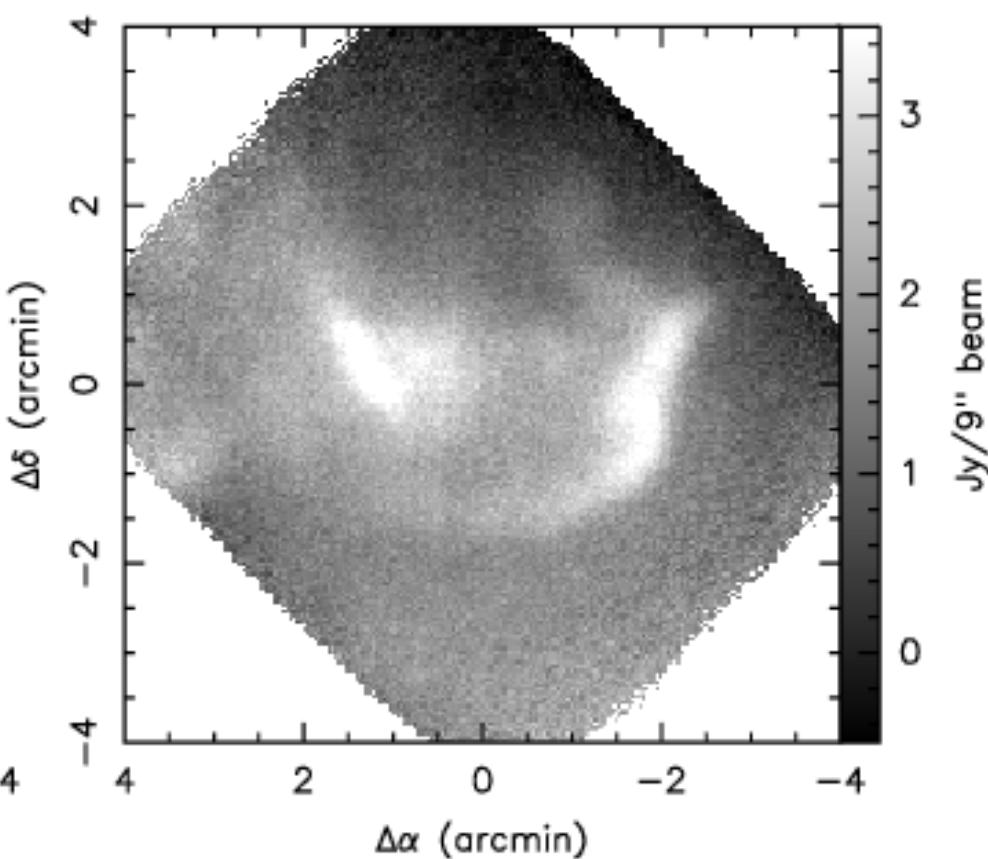
Increasing other Capabilities on SOFIA

- Use Occultation Cameras (HIPO & FLITECAM)
- Add Polarimeters
- Expand Wide Field FIR Cameras
 - At 100 um, an 8'x 8' fully sampled array is an 128x128 array

Horsehead Nebula

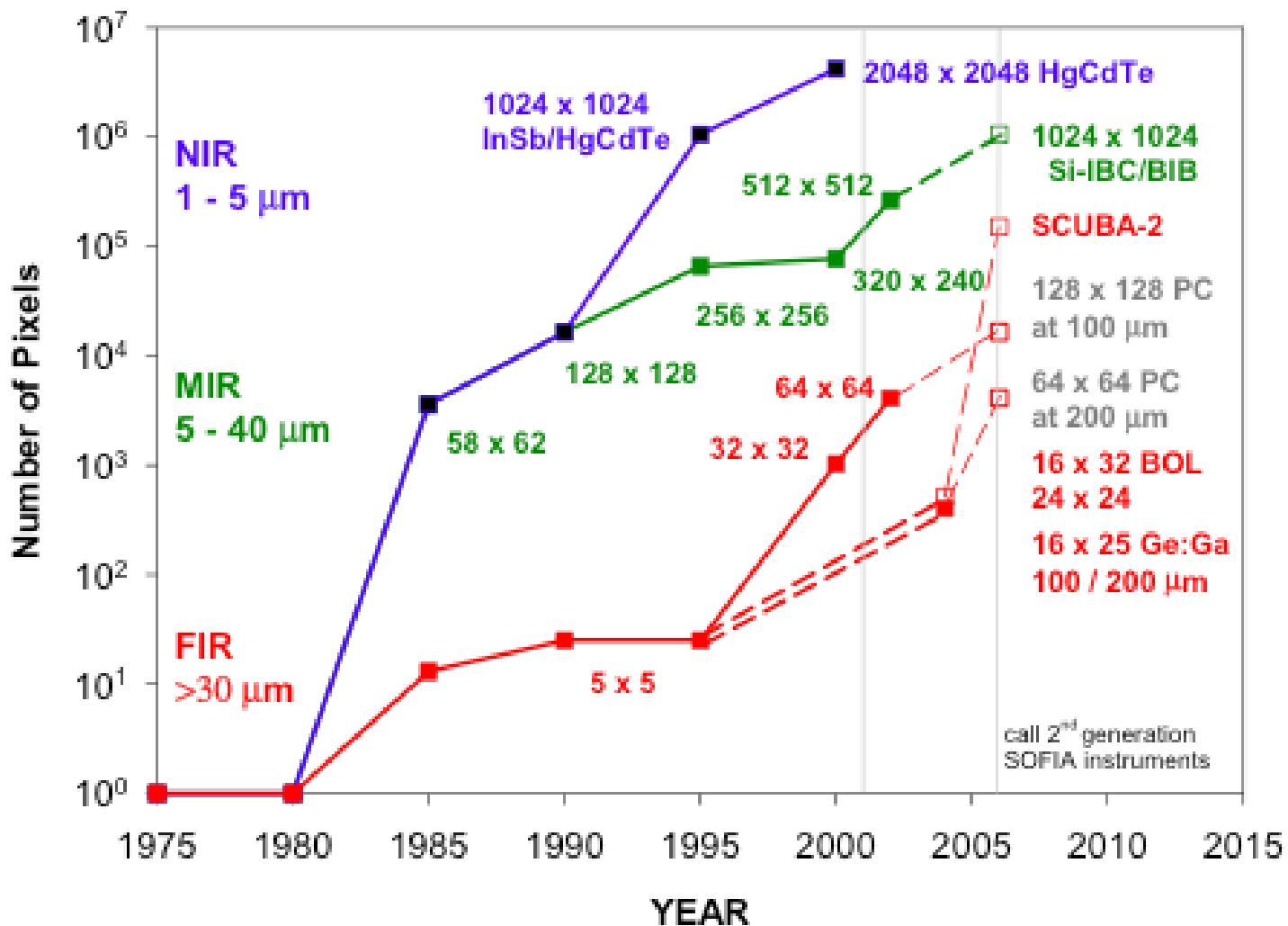


Palomar Sky Survey



SHARC II
350 μ m

Detector Array Capabilities



Wolf 2002⁴⁹

SOFIA supports the larger IR/SMM Technology Development Community

http://www.sofia.usra.edu/det_workshop/



FAR-IR, SUB-MM & MM DETECTOR TECHNOLOGY WORKSHOP



Organized & Sponsored by NASA/Ames & USRA/SOFIA

1-3 April 2002

Monterey, California



**Infrared, Sub-MM & MM Detector
Working Group - Final Report**

Purpose	Program	Working Group Final Report	Workshop Posters	Workshop Manuscripts	Workshop Location	Organizers & Participants
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This workshop is endorsed by:



The image contains two logos. On the left is the NASA logo, which consists of the word "NASA" in a serif font inside a circular emblem with a stylized American flag. To its right is the DLR logo, which features a stylized white "X" or arrowhead shape inside a circle with the letters "DLR" below it.

Beyond Spitzer & Herschel....

- Hopefully new IR/SMM space missions
- BUT also, until the mid- 2020s, a vibrant IR/SMM airborne program (**SOFIA**) providing
 - Easy access to the IR/SMM Universe
 - State-of-the-art IR/SMM science instruments
 - A source of resources for new IR/SMM technology development
 - An advocate for the IR/SMM community
- **SOFIA** is the far-IR community’s “ground-based” observatory with many space-based type capabilities

So how & when can the community use SOFIA?

- SOFIA will have an annual observing cycle
 - Call for Proposals will be issued by USRA annually
- Observing will start in **January 2006**

SOFIA

Stratospheric Observatory for Infrared Astronomy



Jackie Davidson
(USRA SOFIA Project Scientist)

<http://sofia.arc.nasa.gov>